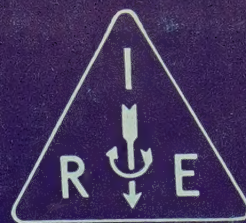


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Participants: C. B. Plummer, FCC H. Magnuski, Motorola K. L. Neumann, Radiomarine J. S. Smith, General Electric J. Keller, User Groups	

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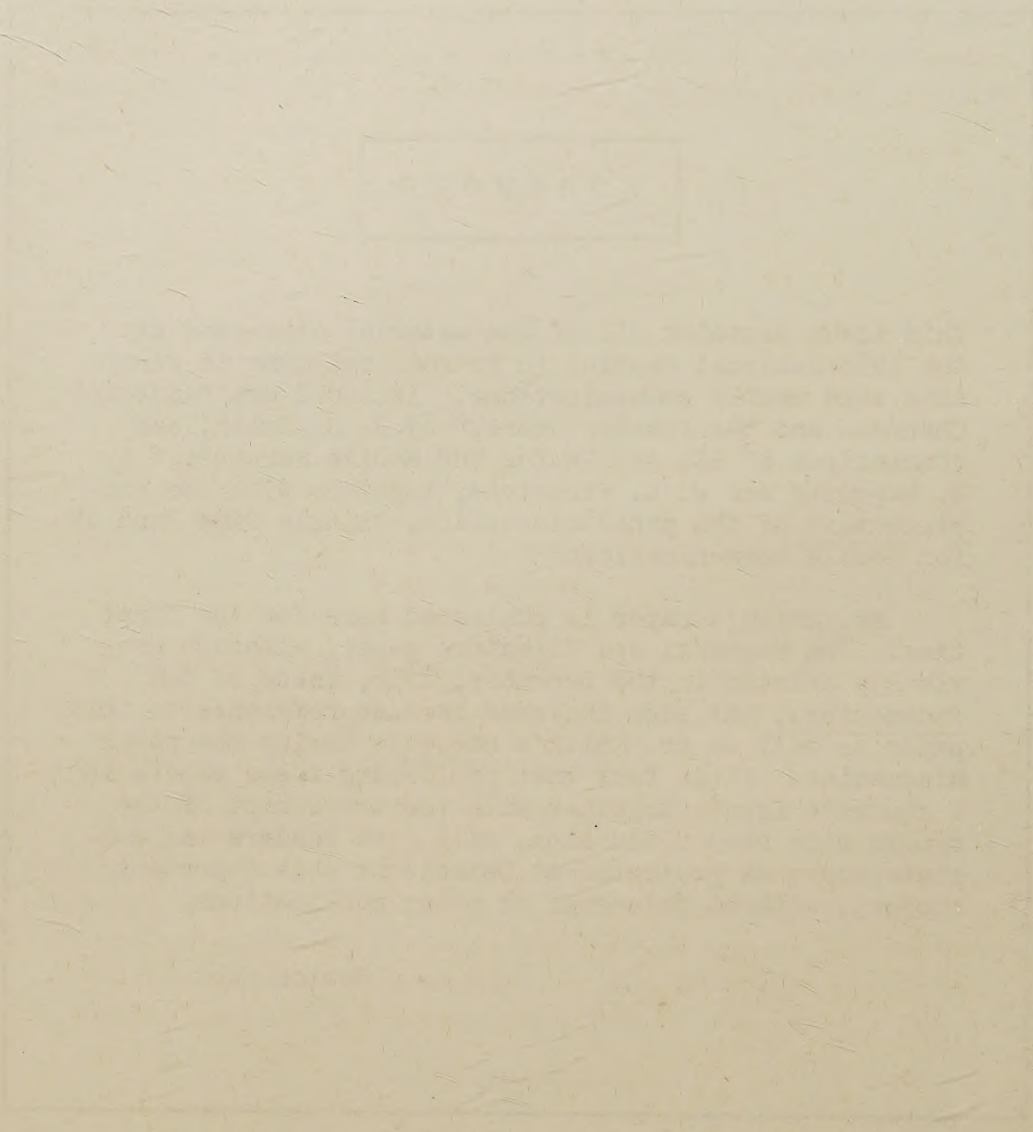
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FOREWORD

This issue contains all of the material discussed at the 1956 National Meeting in Detroit relating to single side band mobile communications. Included are "Adjacent Channels and the Fourier Curse," by J. S. Smith, and "Comparison of SSB and FM for VHF Mobile Services," by H. Magnuski and W. L. Firestone, together with the complete text of the panel discussion, "Single Side Band AM for Mobile Communications?"

Mr. Smith's paper is published here for the first time. The Magnuski and Firestone paper, although previously printed in the December, 1956, issue of the Proceedings, has been included because reference to this paper as well as Mr. Smith's was made during the panel discussion. It is felt that publishing these papers in a separate issue, together with the transcript of the single side band discussion, will give readers the complete story as presented at Detroit on this important subject, without reference to other publications.

Newton Monk



ADJACENT CHANNELS AND THE FOURIER CURSE

Jared Scott Smith
General Electric Co.
Syracuse, N. Y.

Summary

This paper shows the results of measurements of adjacent channel interference due to wide and narrow band FM, AM, and SSBAM transmitters. A brief analytic discussion is made to illustrate why the expected results are obtained and a functional method of measurement is described. The measured transmitters were of a standard available commercial design except that in some cases filters were added for audio cut-off to show the possible improvement in performance due to restriction of audio band pass to the modulator.

Results indicated that at 20 K.C., the narrowest spacing common in mobile radio use, there was little difference between the narrow systems of modulation. At closer spacings than 20 K.C. the SSB transmitter showed limitations due to noise. At closer spacings than 20 K.C. the results for FM were obscured by the limitations of the receiver selectivity.

Historical Development

Since the earliest days of radio communication, engineers have been fighting the battle of bandwidth versus information.

Back before Shannon, Hartley's Law and information theory some investigators proposed the use of FM of very narrow deviation as a means of reducing bandwidth requirements. Using 1 K.C. swing they conjectured to transmit signals of many K.C. In 1922 J.R. Carson showed mathematically that, regardless of deviation, the information bearing side bands were displaced on either side of the carrier by a spacing equal to the modulating frequency. Furthermore, a Fourier analysis of the frequency components of voice showed that some of these sidebands could be quite widely spaced from the carrier. Worse than that it was easy to show that FM with its inherent Bessel distribution of side frequencies could, only in the limiting case, approach the band width of AM. This pretty well rang the death knell of FM until 1936 when Major Armstrong, while claiming no bandwidth advantage, showed pretty conclusively that a 25 to 30 db advantage for most forms of noise could be gained by the use of FM. The obvious advantage of this form of communication for mobile reception, where wide signal level variations constantly pitted signal strength against high ambient noise levels, was soon recognized and FM has been the standard of the Mobile Communications industry for almost 20 years.

The Need For Better Performance

As time has gone by, the occupancy of the Mobile Communications bands at 30, 150, and 450

megacycles has increased to the point where it has become necessary, at least at 150 megacycles, to split in half, from 60 to 30 K.C., the original adjacent channel spacings. At the rate at which occupancy is increasing, it is inevitable that, in time, similar steps will have to be taken in other bands; and it may be that eventually even closer channel spacings will be come desirable. With these thoughts in mind, much attention has recently been given to schemes of reducing bandwidth requirements and minimizing unwanted modulation products and noise from transmitters in adjacent channels.

One of the schemes receiving the most widespread attention at this time is SSBAM. Taking a leaf from the pages of telephone practice, where it has long been successfully used to conserve bandwidth, there are many who propose that single sideband could similarly result in a "two to one reduction in bandwidth", for Mobile Communications. While such a saving is very nearly true in a multiplex scheme with nearly equal desired and undesired signals, let's examine the results of using the same approach in mobile service, and at the same time compare the adjacent channel performance of FM and AM systems suited for mobile use.

The Distortionless System

From a theoretical standpoint, FM as a scheme of modulation, with its aforementioned Bessel sideband distribution, seems to be inherently a wide band scheme compared to AM of any form where the transmission band need ostensibly consist of only first order sidebands of the modulating frequency. For single tone modulation, in a distortionless system, the two schemes can be expressed as:

AM:

$$e = A_0 \sin \omega t (1 + M_a \sin \omega_s t)$$

ω = Angular velocity or r.f.

ω_s = Angular velocity of a.f.

M_a = Modulation index,

= % from 0 to 100

If we expand:

trigonometrically:

$$e = A_0 \sin \omega t + \frac{M_a A_0}{2} \cos(\omega t - \omega_s t)$$

$$- M_a A_0 \cos(\omega t + \omega_s t)$$

FM:

$$e = A_0 \sin(\omega t + M_f \sin \omega_s t)$$

M_f = modulation index

$$= \frac{\text{swing in K.C.}}{\text{audio in K.C.}}$$

by Fourier into Bessels:

$$e = A_0 \sum_{n=-\infty}^{\infty} J_n(M_f) \sin(\omega + n\omega_s)t$$

The AM spectrum consists of just a carrier and two side bands. For a SSB system the carrier and one sideband could be suppressed leaving a spectrum of just a single frequency. For FM the Fourier expansion has presented us with an FM spectrum with components extending from zero to infinite frequency spaced by the frequency of the audio signal. Now, if a non-periodic complex audio wave, such as voice, is the impressed signal, it is possible to describe an envelope spectrum by the Fourier Transform such that in the AM case a pair of frequency spectra, whose extent is limited by the audio pass band of the modulator, appear symmetrically placed on either side of the carrier. Again for SSB only one such spectrum is required to bear the intelligence. In the FM situation we once again have a spectrum extending to infinity in both directions about the carrier with the added complication that, unlike AM, where multitone modulation simply results in a linear superposition of sidebands, we have in addition, sidebands located at the sum and difference frequencies as well as at the individual harmonics of the modulating frequencies. The total energy of all these FM sidebands is always equal to that of the unmodulated carrier and fortunately most of this energy is within or near the band of frequencies displaced about the carrier by the amount of frequency deviation. Some of it, however, unlike distortionless AM, is bound to fall into the adjacent channel.

The Effects of Distortion on AM and SSB

DSB AM or SSB in its pristine state as described in the previous paragraph is actually not attained in practice for, it is not possible either to modulate nor amplify in a truly distortionless manner. In both processes, modulation or amplification, the inherent non-linearities of realizable equipment produce harmonics of and mixes between the components of the modulating spectrum.

Non Linear Amplification - Single Frequency

$$e_{out} = a_0 + a_1 e_g + a_2 e_g^2 + a_3 e_g^3 + \dots a_n e_g^n$$

If $e_g = k \cos \omega t$ (unmodulated carrier in AM or Single tone modulation in SSB)

$$e_{out} = a_0 + a_1 K \cos \omega t + a_2 K^2 \cos^2 \omega t + a_3 K^3 \cos^3 \omega t + \dots a_n K^n \cos^n \omega t$$

by trigonometric expansion we obtain the Fourier Series:

$$e_{out} = (a_0 = \frac{a_2 K^2}{2} + \dots) + (a_1 K + \frac{3a_3 K^3}{4} + \dots)$$

$$\cos \omega t + (a_2 K^2 + \dots) \cos 2\omega t + (a_3 K^3 + \dots) \cos 3\omega t + \dots$$

(constant term may be neglected in r.f. amplifier)

This result shows the production of harmonics of the driving signal - similar to the familiar case of the non-linear class C amplifier. For two frequencies the non-linearities produce signals close to the carrier:

Non Linear Amplification - two frequencies

$$e_{out} = a_0 + a_1 e_g + a_2 e_g^2 + a_3 e_g^3 + \dots a_n e_g^n$$

$$\text{If } e_g = k_1 \cos \omega_1 t + k_2 \cos \omega_2 t$$

by trigonometric expansion:

$$e_{out} = (a_0 + a_2 (k_1^2 + k_2^2) + \dots)$$

$$+ f_1(a, k) \cos \omega_1 t$$

$$+ f_2(a, k) \cos \omega_2 t$$

$$+ f_3(a, k) \cos 2\omega_1 t$$

$$+ f_4(a, k) \cos 2\omega_2 t$$

$$+ f_5(a, k) \cos (\omega_1 + \omega_2) t$$

$$+ f_5(a, k) \cos (\omega_2 - \omega_1) t$$

$$+ f_6(a, k) \cos 3\omega_1 t$$

$$+ f_7(a, k) \cos 3\omega_2 t$$

$$+ f_8(a, k) \cos (2\omega_2 + \omega_1) t$$

$$+ f_9(a, k) \cos (2\omega_2 - \omega_1) t$$

$$+ f_{10}(a, k) \cos (2\omega_1 + \omega_2) t$$

$$+ f_{11}(a, k) \cos (2\omega_1 - \omega_2) t$$

(Constant term may be neglected in r.f. amplifiers. This might be summarized:

$$e_{out} = \sum_{n=1}^{\infty} f_n(a, k) \cos n\omega_1 t + \sum_{p=1}^{\infty} f_p(a, k) \cos p\omega_2 t$$

$$+ \sum_{n=1}^{\infty} \sum_{p=1}^{\infty} f_{n,p}(a, k) \cos (n\omega_1 t \pm p\omega_2 t)$$

In the practical case, therefore we are faced with an infinite spectrum of sideband currents for AM and SSB just as in the case of FM. The result of these unwanted products is an extension of the significant r.f. sideband components in the r.f. spectrum beyond a theoretical minimum width equal to the modulating signal bandwidth.^{21,22,23,20} In SSB the effect is particularly bad because the 3rd, 5th, and 7th order mixes fall in close to the carrier and may occupy the region in which suppression is desirable for the sake of bandwidth saving. The actual magnitude of these undesired side currents could be determined by measuring the linearity of the amplifier under consideration on an oscilloscope with driving voltage as the abscissa and output voltage as the ordinate. This should give a straight sided figure for perfect linearity, so that $e_{out} = a e_{in}$. If the figure is not straight sided then the coefficients in the series a_2 through a_n can be calculated on a basis of the ordinate heights for equal increments along the abscissa. Actually this oscilloscope presentation is commonly used in AM and SSB systems to check on modulation and amplifier linearity. With a five-inch scope however it is difficult, due to spot width, to detect nonlinearities likely to produce distortion products beyond about 50 d.b. down. In the usual case it is necessary to use wave-analyzer techniques wherein the actual amplitude of each component is measured by a highly selective receiver.^{1,14} A further refinement is to arrange for sweeping the spectrum and providing a panoramic presentation on an oscilloscope of the d.b. ratio of each component below the carrier. The actual amplitude of the distortion products below carrier in well designed and maintained AM or SSB equipment might be 40 d.b. for the 3rd, 50 d.b. for the 5th and 60 d.b. for the 7th but where excessive grid drive is encountered in linear amplifiers, or over modulation in AM transmitters it is possible for the 3rd order products of only 10 or 15 d.b. below carrier to exist.^{5,19,21,22} Such a situation as this can of course be duplicated in FM by excessive deviation but for the purposes of consideration here we shall compare on the basis of two properly designed and maintained systems.

A More Functional Method of Adjacent Channel Interference Measurement

For the purpose of comparing the adjacent channel performance of several systems of modulation the mere knowledge of the magnitude of the interfering sidebands does not provide very definitive information. A more functional method, and the one we shall describe here, consists of choosing transmitters and receivers appropriate to a good state of the art and actually measuring the deterioration in signal to noise ratio on a weak desired signal occasioned by the presence of unwanted side currents from an adjacent channel transmitter. Particular attention should be paid to the "good state of the art" for it was found in preparing for the tests, that some AM and SSB receivers commercially available, were not comparable to normal mobile

FM equipment with regard to selectivity to avoid carrier desensitization and cross modulation interference. This necessitated the design of two special receivers for AM and SSB to allow a fair functional comparison with standard FM equipment. Actually in the FM units measured when the transmitter employed the sharp audio filter some further performance gain from 10 K.C. on could have been made in these equipments too by increased receiver selectivity. In order to evaluate adjacent channel interference standard modulation must be used on all equipments. Since the type of modulation most likely to be producing adjacent channel interference is voice and since it is difficult to choose from among the myriad voice characteristics a standard voice, a modulating signal was chosen which simulates the general voice characteristics. This standard modulating signal, which we shall refer to as VOSIM is synthesised from noise of varying levels. Figure #1 shows the complete test equipment arranged for adjacent channel interference measurement. Here we see the receiver arranged as a noise generator followed by the VOSIM amplifier feeding modulating signal to the transmitter under test. The output from the transmitter passes first through an attenuator where a sample of appropriate level may be taken out and thence into a flat wattmeter. The attenuator is such that its amplitude response is flat over the band of frequencies of concern. The output of this attenuator is sampled by a vacuum tube voltmeter capable of reading r.f. signals at the level of tenths of a volt. This known level of r.f. signal is then passed through a second accurately calibrated attenuator, through a directional coupler which allows insertion of a desired signal, and thence to the measuring receiver. The receiver output is delivered to a resistive load attached to a standard distortion analyzer.

In use, measurements are made in terms of decibels attenuation below carrier or peak power for a 6 d.b. reduction, by the presence of the undesired signal, of a twelve d.b. SINAD ratio originally established by the desired signal. This reference level in the receiver, which is typical of the conditions involved in trying to receive a weak signal is introduced into the receiver from the

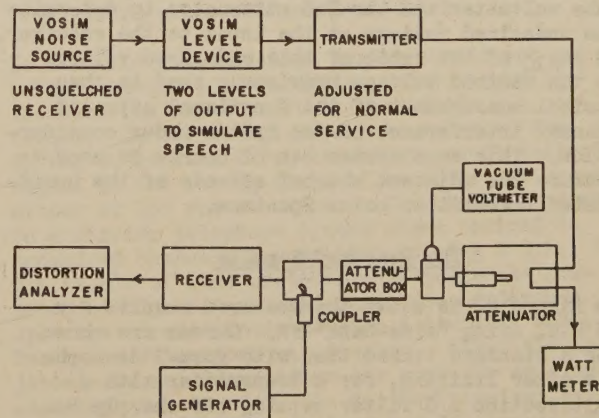


Fig. 1 - Method of measurement.

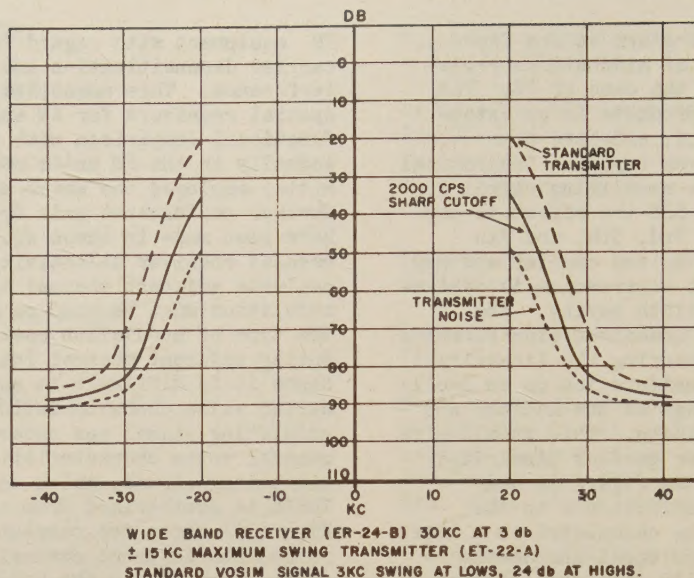


Fig. 2 - FM adjacent channel interference ± 15 kc swing.

desired signal generator and the receiver adjusted for rated power output at rated distortion with $2/3$ rated system modulation. This strong desired signal is then reduced until a measurement of signal + noise + distortion (read with the distortion analyzer rejecting the fundamental frequency of the desired signal) reaches a level of 12 d.b. This is referred to as a 12 d.b. SINAD ratio. The magnitude of desired signal level in volts at the receiver input to produce this ratio may then be determined by removing the desired signal and reproducing this same signal with the undesired transmitter adjusted directly onto the receiver channel and noting the reading of the vacuum tube voltmeter and the attenuator following it. Adjacent channel interference in terms of a further 6 d.b. reduction of the 12 d.b. SINAD ratio due to the desired signal may then be determined in the following manner. With the desired on, and producing a 12 d.b. SINAD ratio, the undesired signal is set to an off channel frequency and its level raised in the 2nd attenuator until the SINAD ratio at the receiver is only 6 d.b., a condition representative of bad interference. A reading is then made of the vacuum tube voltmeter and the 2nd attenuator to determine the undesired voltage at the input to the receiver. $20 \log_{10}$ of the ratio of this undesired voltage to the desired voltage previously read is then a decibel measurement of the functional adjacent channel interference of the system under consideration. This same system can of course be used to measure the adjacent channel effects of the unmodulated transmitter noise Spectrum.

The Measured Results

In figure #2 is shown the measured results for 15 k.c. swing "wide-band" FM. Curves are shown for a standard transmitter with normal de-emphasis after limiting, for a transmitter with a multisection L/C filter cutting off sharply beyond 2000 cps after limiting, and for trans-

mitter noise alone. In all of the measured curves for FM "transmitter noise" represents the interference obtained in the absence of modulation. In the 80 to 90 d.b. level this is caused by transmitter noise however at lower levels it is an indication of the receiver side wall selectivity.

Curve #3 is similar to number 2 except that it is for 5 k.c. swing or "narrowband". The curve taken with the 2000 cycle filter shows that the sideband slope of the transmitter is approaching the side wall slope of the measuring receiver.

Curve #4 is similar to the previous two FM curves except that "sliver-band" deviation of only 2.5 k.c. swing is used. Here the use of the 2400 c.p.s. filter brings the transmitter sideband slope just about equal to the measuring receiver sidewall selectivity.

Curve #5 shows the interference in the case of double sideband AM. The worst curve shown, just under 100% modulation may not be typical of actual performance since the Commercial transmitter itself contained no overmodulation prevention provisions. During the tests however the modulator was supplied with audio from a limiter amplifier so that no overmodulation occurred on peaks. This transmitter did not have the carrier suppressed. While tests with completely suppressed DSB AM were not made there is evidence to indicate this would not alter materially the sideband distribution.

Curve #6 shows the interference measured from a SSB AM transmitter. R.F. feedback was used for good output amplifier linearity. No means of preventing grid current in the output amplifier was used. Instead the audio signal was, as in the AM case, fed to the transmitter through a limiter amplifier so that operation above or below grid current could be easily controlled.

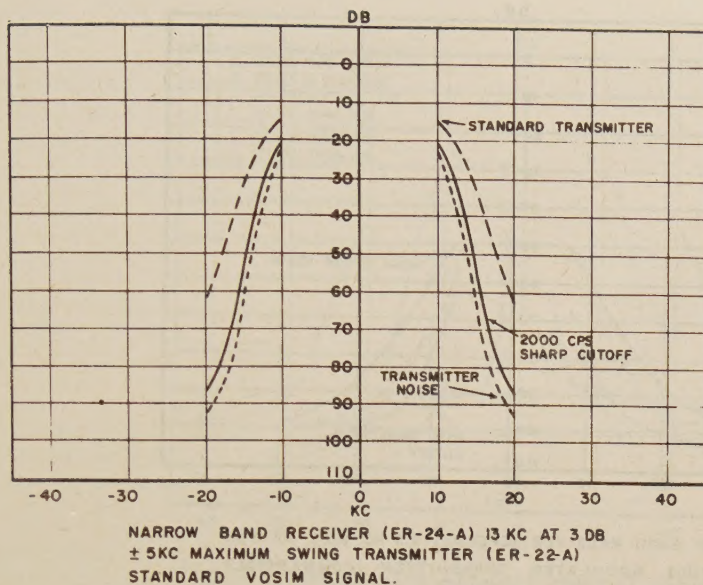


Fig. 3 - FM adjacent channel interference ± 5 kc swing.

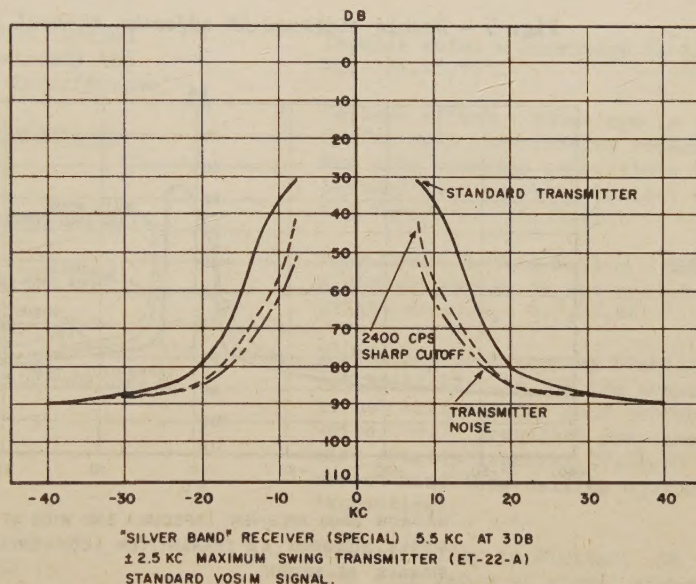


Fig. 4 - FM adjacent channel interference ± 2.5 kc swing.

Two curves, solid noise, and standard VOSIM are shown with grid current flowing to allow comparison with the more desirable condition, standard VOSIM with no current.

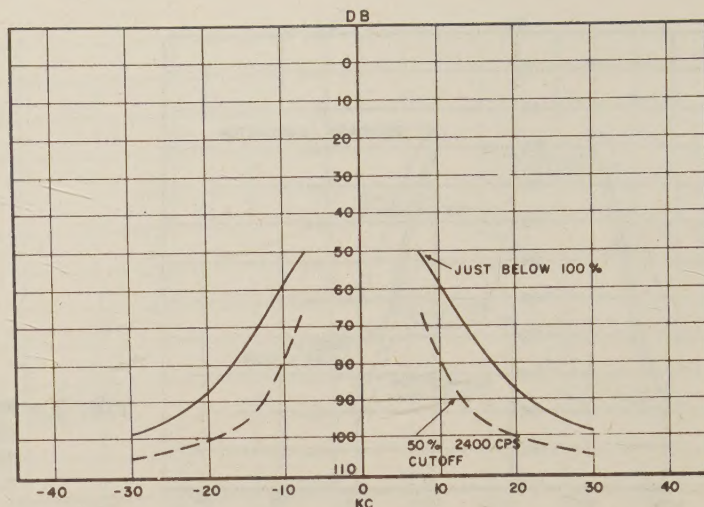
Comparison of the Systems

If we are to compare the various systems with an eye towards bandwidth consumption it is probably best to compare the best state of the art in each case. Curve #7 therefore shows the five different modulations 15 k.c. FM, 5 k.c. FM, 2.5 k.c. FM, DSBAM, and SSBAM. In each case the curve is the one obtained with the previously described techniques which resulted in the least adjacent channel interference.

While we have set up a very functional standard of adjacent channel performance in the 12 d.b. to 6 d.b. SINAD reduction there is one further

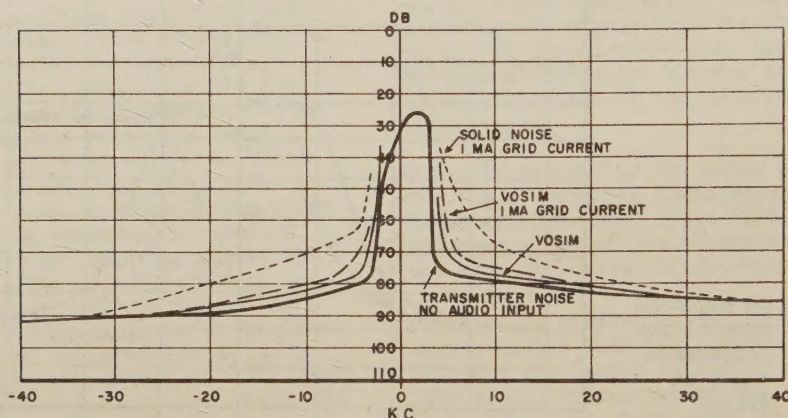
consideration which has an immense bearing on actual systems operation. This is the range of required adjacent channel protection.

In a mobile communication system consistent use is made of areas of reception which result in the need for a protective range of 130 d.b. or better. In the actual case this means we are trying to receive a fractional microvolt desired signal in the strong field of an undesired transmitter of 250 watts or more. This is in contrast to a carrier telephone system where desired to undesired channels are maintained at ± 2 d.b. The net result of wide protective range in the presence of adjacent channel interference depends upon the circumstances of each individual case. Two basic situations may develop. First the adjacent channel transmitter may open the squelch and cause "chatter" in the desired receiver over a large area when the desired transmitter is off



NARROW BAND RECEIVER (SPECIAL) 5.5 KC WIDE AT 3 DB
AMPLITUDE MODULATED TRANSMITTER (COMMERCIAL)
STANDARD VOSIM SIGNAL.

Fig. 5 - Double sideband AM adjacent channel interference.



NARROW BAND RECEIVER (SPECIAL) 3 KC WIDE AT 3 dB
SINGLE SIDEBAND AM TRANSMITTER (COMMERCIAL)
SIGNALS AS SHOWN.

Fig. 6 - Single sideband AM adjacent channel interference.

but if the desired signal, when on, is strong in this area it will "capture" the receiver and no loss of message results. In the other case, where the desired is weaker than the adjacent channel, then you are faced with complete loss of the message. While the former situation could be resolved by tone operated squelch, the latter cannot.

Probably the most deleterious effect that the wide protective range requirement imposes is in mil-ling to a large extent the theoretically possible 2:1 bandwidth saving attributable to SSBAM. Reference to curve #7 shows how this happens. If we draw a horizontal line through 10 d.b. SSBAM appears capable of very limited bandwidth with virtually no space required for the suppressed sideband. (While not shown on the curve the two

tone intermodulation products were between 30 and 40 d.b. down in the desired channel.) If we draw the same line at 70, 80, or 90 d.b. we find that the apparently suppressed sideband is actually capable of the 12 to 6 d.b. SINAD reduction quite a ways out in frequency on the side of the "un-used channel". Clearly, for such large protective ratios we could not use that part of the spectrum without experiencing severe interference.

With maximum protective range as the most desirable criterion, investigation of the various curves in figure #7 at 20 kilocycles, the narrowest channel spacing in common usage, shows the interesting fact that except for the singular case of DSBAM at 50% modulation, there seems to be little choice between the narrow band modulations and shows the disturbing fact that trans-

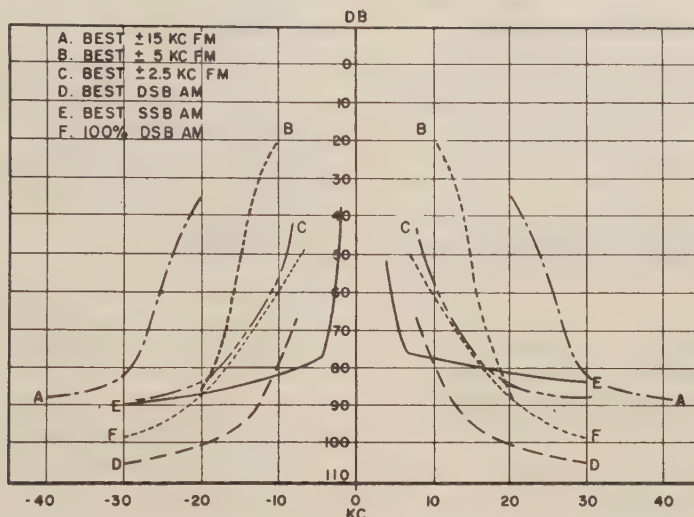


Fig. 7 - Comparative adjacent channel interference --
fm, AM, SSB.

mitter noise, where measurement is not limited by receiver bandwidth, seems to be already the item which is limiting reduction of interference.

At 20 KC: Best Performance, db

± 5 kc FM	87
± 2.5 kc FM	84
2.4 kc DSBAM	87 (100%) - 102 (50%)
3 kc SSBAM	87, (L) - 81, (u)

At 20 KC: Noise Level, db

± 5 kc FM	93
± 2.5 kc FM	84
2.4 kc DSBAM	below 102
3 kc SSBAM	88, (L) - 82 (u)

Examination of the individual curves shows that except in the case of DSBAM transmitter, noise is only a few d.b. below the modulation spectrum. Curve #7 shows DSBAM at 50% modulation as the best performance for AM but it is really not fair to make comparison on this basis without allowing a similar reduction in deviation for the FM systems. At 30 kilocycles spacing, the influence of transmitter noise is such that there is still little systems performance gain available through the use of the SSB AM transmitters as opposed to narrow FM. DSB AM appears somewhat better because of less noise.

There are of course quite a number of other factors besides modulation spectra and transmitter noise, which, while not the subject of this paper, are deserving of mention because they are important considerations in choosing a modulation system for mobile service. A few of the more important of these are briefly:

1. Impulse noise - Advantage is in favor of FM. 11,15,35
2. Capture effect - Advantage is in favor of FM for skip interference reduction and for area coverage in multiple transmitter systems such as state police, pipe lines and thruways. 15,35,29
3. Peak Power VS Tube Rating - SSB leads if a strong carrier is not needed for stability reasons. 6,7,27,28
4. Stringency of Frequency Stability - FM not critical. In SSB the present .0005% is not adequate for good performance on voice. 6,7 Transient response is even more greatly impaired. 19,26,30 Use of narrow band tone calling equipment is impractical.
5. Susceptibility to Flutter. FM is good over wide range of signal strength with rapid variation. SSB and AM are likely to suffer both in range and rapidity of attenuation variation - the latter due to AVC time constants.

In recapitulation it would appear that, while the theoretical advantages of narrow band modulation schemes appear very promising the present state of the art places narrow spacing in competition with protective range and does not allow their full advantage to be derived in mobile communication service. Many of the problems which prevent their full utilization in this service are presently under investigation and, while a 3 k.c. spectrum for 3 k.c. intelligence does not appear feasible for a long time in the future, it is reasonable to expect that continual attention to design and maintenance can yield great improvement in the adjacent channel performance of mobile transmitters. It is interesting to note that, if economics may be justified as an engineering problem, the

largest performance advantage can be gained by detailed attention to station transmitters where power and antenna advantage often result in their being the controlling item in system performance.

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COMPARISON OF SSB AND FM FOR VHF MOBILE SERVICE

H. Magnuski
W. Firestone

Summary

Mobile SSB and FM systems are compared on the basis of the same equipment size. The influence of the speech processing on the comparative results is discussed. It is concluded that SSB may provide a somewhat better range of operation with considerable spectrum saving but the S/N ratio in strong signal areas will be poorer.

My remarks will be strictly limited to the use of SSB for mobile service, voice communication in VHF band above 30 mc and not to other SSB applications.

There are two major questions to answer. 1. Will SSB be suitable for VHF mobile application and how well it will perform in comparison to FM or to put it bluntly, will all FM systems become obsolete overnight? The second question is: Why bother with SSB in the first place, will it really save the frequency spectrum and provide more channels?

In my paper I will try to cover the first question, the second will be only briefly mentioned; the answer to it is complex and not an obvious "yes", or "no."

In comparing SSB and FM some engineers previously based the comparison either on equal transmitter peak power or equal average power, or what not; some claim that SSB is better than FM by 9 db, some think it is 20 db or more better and some others think that it is no darn good at all. I am not questioning these figures, they are all correct, relative to the assumptions made in comparing the systems.

Basis for Comparison

Since the two systems (SSB and FM) are quite different, one must first agree what system features we are after and what equipments we are about to compare. For mobile operation, only voice modulation will be considered and the range of operation will be of primary importance to us.

For range determination, threshold conditions and small S/N ratios, approaching unity, will be of interest, and further, the results will not be the same as in strong signal areas, where the FM, due to the so-called improvement factor, will, as a rule, provide a somewhat better S/N ratio.

In comparing the equipment, the same operating frequency and the same receiver noise figure is assumed, but not the same bandwidth. Otherwise the receivers will not differ much in size, cost and complexity. A more difficult task is the transmitter comparison. In mobile applications, the size, cost and power drain are most important; hence, it is felt that the most logical

assumption would be to have the same size equipments. It is further assumed that the size of the transmitter is a function of power dissipated in it, and furthermore, that most of the power is dissipated in the final RF power amplifier. Thus to simplify the assumptions, the following comparisons will be based on the same dissipated power in final RF amplifier tubes during the normal speech loading of the transmitter or to say it differently, the same output tubes will be used to their full capability in both transmitters. Figure 1 shows the two transmitters built using this assumption and one may see that they look

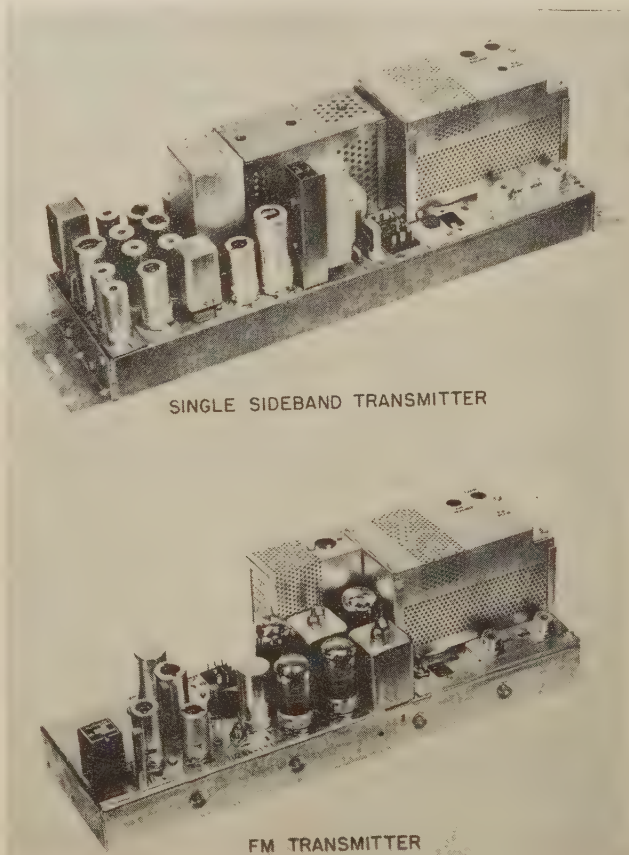


Fig. 1 - SSB and FM Transmitters.

substantially the same and off-hand no one could tell that the top one is a SSB transmitter.

Transmitter Power Limitations

There is no problem in measuring transmitter power in FM systems and the power output, dissipation, and efficiency of the transmitter are substantially independent of modulation. Unfortunately, the same cannot be said of SSB, where both the power output and efficiency, and as a result the dissipation, are a complex function of the

modulating signal. Thus, to estimate the power output of a SSB transmitter, first it is necessary to describe the character of the modulating signal.

Figure 2 represents typical power distribution in human speech vs time. We can see that the power peaks exceed the average power by some 20 db for short periods of time. On the other hand, for

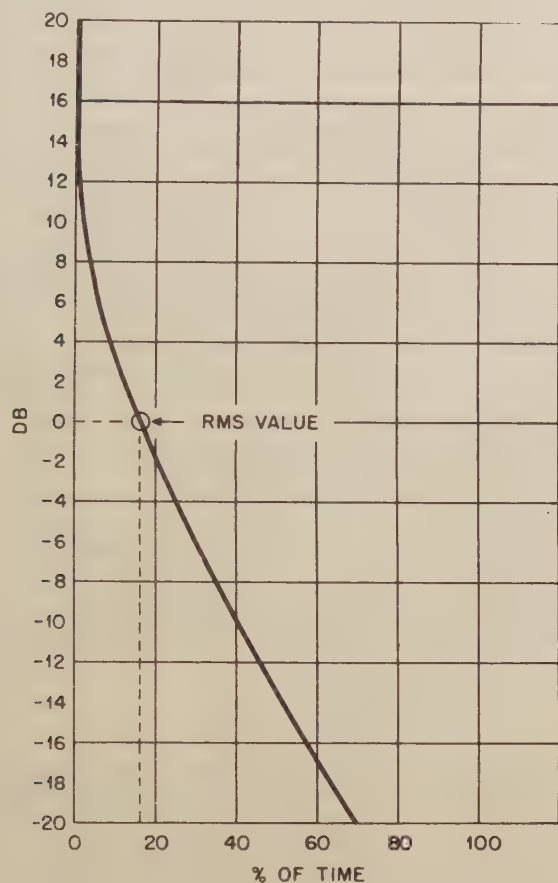


Fig. 2 - Percentage of time voice spends above a given level.

some 25% of time there is no power at all. Obviously, to transmit such unmodified speech, the equipment would have to have a very high peak power capability vs average power. This would greatly decrease the transmitter efficiency, and received signal to noise ratio and therefore is never done. In an FM system, the maximum deviation is limited by the receiver bandwidth and cannot be exceeded without serious distortion and introduction of noise into the receiver. Thus, FM systems are very definitely peak limited. If we would have to transmit the modulating signal with high peak to average power ratio, through an FM system, then the average deviation would be very low and the recovered signal to noise ratio would also decrease in proportion. Such an FM system would look very bad indeed.

In a SSB system, there is not a definite peak power limitation and one can select the transmit-

ter operating point and supply voltage in such a way that high peaks can be transmitted with relatively low average power. However, such a set-up leads to a low average efficiency of the transmitter resulting in high dissipation and a small average output power again. Therefore, all practical mobile systems do not transmit undistorted speech with unlimited peak to rms ratios and some kind of speech processing is always used to improve the received signal to noise ratio. The speech waveform distortions we refer to are not to be confused with the audible distortions as experienced by the human ear. Considerable waveform distortion can be tolerated by the ear before it senses any distortion.

Speech Processing

By speech processing it is meant any scheme which distorts the original speech, including changing the ratio of peak to average power and changing the amplitude vs frequency distribution. Speech can be processed in any number of ways and to any degree desirable and there are practically as many processes as there are engineers designing the equipment. Usually the processing consists first of clipping the peaks; second, emphasizing high frequencies, and third, filtering the high frequency components (either existing in the original speech or created by the clipping process), as well as low frequency components which are difficult to transmit and deemed unnecessary to preserve the intelligibility of the speech. Deviation limiters, speech clippers, compressors and other gain control amplifiers as well as pre-emphasis will all fall under these general categories of speech processing. It is not within the scope of this paper to discuss the relative merits of all the different methods of speech processing and only two general statements will be made.

First, the more the speech is clipped or otherwise processed, the stronger the average speech power detected will be at the receiver and therefore the better the signal to noise ratio. This obviously helps legibility in high noise conditions. On the other hand, the more speech is processed the more distortion is introduced, which has the opposite effect. In general, a compromise has to be reached between these two factors in order to obtain the maximum possible intelligibility. In comparing FM and SSB systems, one can see that in an FM system a higher degree of speech processing will be desirable than in single side band, because the average deviation increases in proportion to the clipping of the peaks, while in single side band the average power usually changes only slightly with clipping, mainly due to the changes in transmitter efficiency. This is true only if the SSB transmitter design is optimized in each case for the particular processed speech it is expected to transmit. We can conclude that if both systems are optimized for best intelligibility, speech transmitted through the single side band system would be less distorted than in an FM system.

The second statement is that because of the differences in speech processing between different

systems, the results of the comparison between FM and single side band which are to be discussed, are only as good as the assumption made as to the speech processing. Practical systems, when compared, may differ a few db one way or the other depending on what kind of speech processing was included in them. Therefore the answer to the question regarding which system will provide a better range and better signal to noise ratio is complex and no complete agreement is expected between engineers, even after reading this paper. In an FM system, we assume an intensive clipping or instantaneous deviation limiting giving a peak to average value of about 6 db (3 db more than undistorted sine wave). This assumption will also mean that in FM the detected speech power will be 3 db below the power of the test signal causing full deviation. For single side band operation, a statistical experiment on a small scale was performed in order to decide how much to process the speech for best intelligibility. The result of this ex-

S/N db	0	-3	-6	-9
P_k/RMS db	PERCENTAGE READABILITY			
15.1	100	63	20	0
12.2	100	63	20	0
9.5	100	56	10	0
7.6	100	43	0	0

Fig. 3 - Percentage readability for voice at various clipping levels.

periment is shown on Figure 3. This table shows the readability in signal to noise ratios of unity, -3 and -6 db and for different amounts of clipping.

By signal to noise ratio it is meant the average speech power (after it was clipped and filtered by a bandpass filter) to the average white noise power. One can see that one can clip the speech so that after filtering, the peak to rms ratio is reduced to only 9.5 db and still the readability (in noise, which is twice as strong as the average speech power) is 56%, or almost as good as with unclipped speech which was 63%. This condition was selected for comparison of the SSB and FM systems. Another processing assumed was preemphasis of high frequencies. Figure 4 shows a typical power vs frequency distribution in human speech. One can see that high frequencies can be considerably preemphasized (up to 25 db at 3000 cps) to make this energy distribution uniform at all frequencies. The assumed preemphasis was 16 db at 3000 cycles for both systems. At the receiving end complementary deemphasis was assumed. It is to be noted here that the deemphasis circuit benefits the FM receiver much more than SSB receiver as shown on Figure 5 because of parabolic noise power distribution in FM receivers in strong signal areas. By deemphasizing the high frequency response of the receiver, we also cut down the high frequency noise and in FM systems most of the noise power is at the higher frequencies. The resulting noise spectra are presented on Figure 5. These factors were evaluated and were found to be, for an FM system, 10.7 db advantage, and for a single side band system, 6.8 db advantage, over the systems not using preemphasis. This factor will not influence the range of the FM system and will only improve the S/N ratios in a strong signal area. However, in SSB, the range will be increased because deemphasis effectively narrows the bandpass of the receiver and thus decreases the noise power.

Transmitter Power

After one has decided on processing the modulating signal to be used with the SSB transmitter, an optimum transmitter design has to be consider-

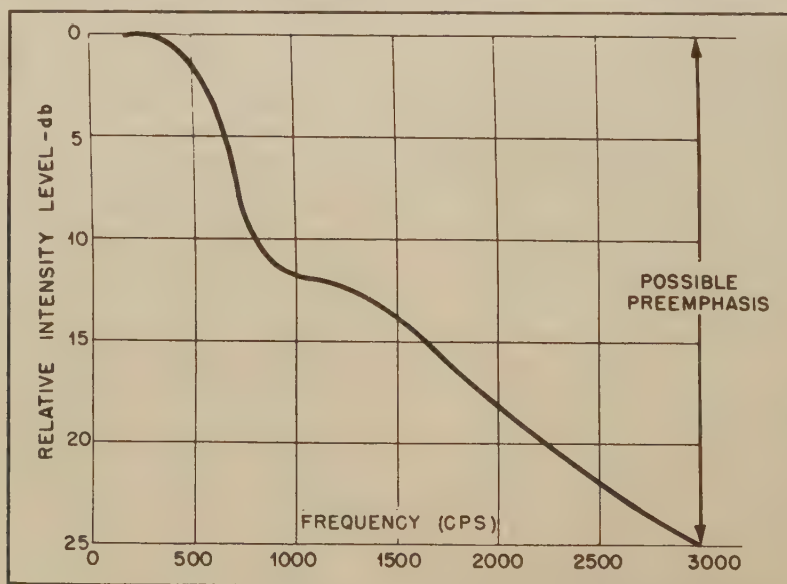


Fig. 4 - Power vs frequency distribution of speech.

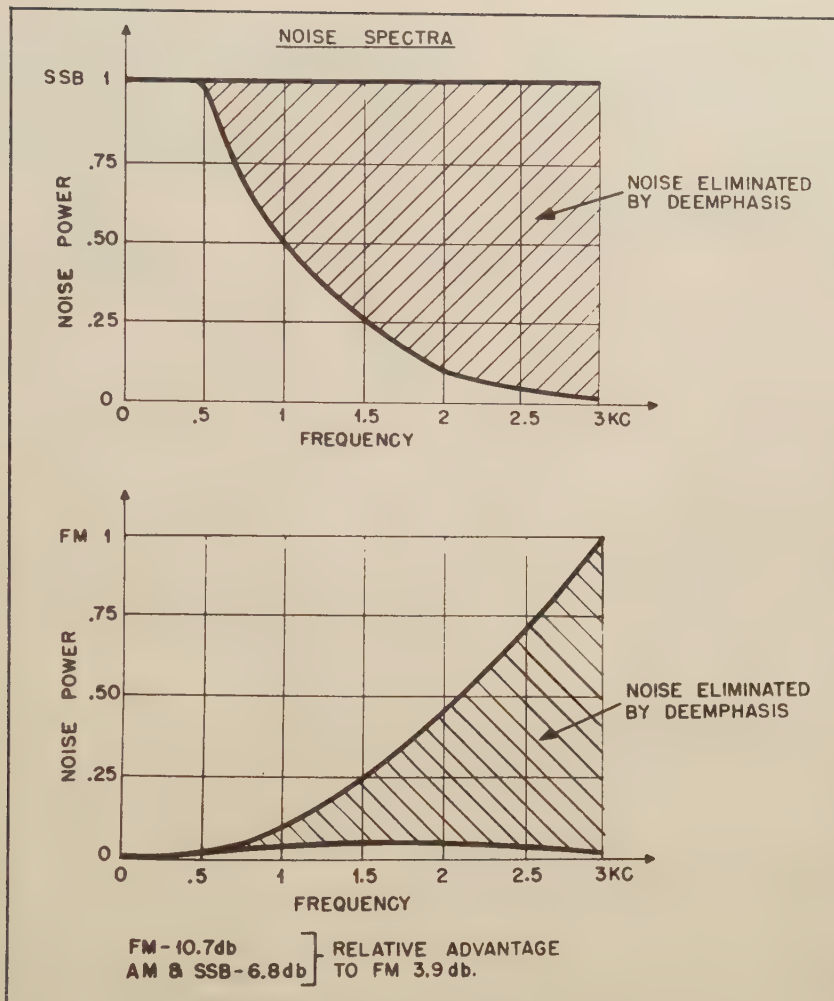


Fig. 5 - Improvement in S/N due to deemphasis.

ed. For a given output tube with a given maximum dissipation and a given plate voltage, the modulating signal (consisting of clipped speech) can be increased to a certain value before one of two things occur, a) full tube dissipation may be reached, b) the peaks may exceed the peak power capability of the transmitter and additional distortions and/or peak clipping may occur before the full dissipation is reached. To optimize the design of the transmitter, the selection of the supply voltage and tube operating point should be such that these two things, namely the full power dissipation and peak clipping, should occur at the same time. In this case, a maximum, average output power for a given processed speech input will be reached. One can see that a different transmitter design will be necessary for different assumed speech processing. Also, obviously some means has to be included to protect the transmitter from overloading in case the input signal is different from the one which was assumed for the design. Figure 6 presents the comparison of transmitter output powers for the experimental FM and SSB transmitters which were shown on Figure 1 and were built, based on the above assumptions. One can see that the average power in the antenna

of an SSB transmitter will be lower by 4.7 db. I may add that this is perhaps the most disadvantageous assumption for SSB and is not the same as a comparison based on equal drain - which would show

	FM	SSB
DC PLATE VOLTAGE	560V	625V
TOTAL INPUT TO RF AMPL.	120 WATTS	80 WATTS
DISSIPATION IN FINAL RF AMPL.	60 WATTS	60 WATTS
RF OUTPUT AVERAGE	60 WATTS	20 WATTS
RF OUTPUT PEAK	60 WATTS	178 WATTS
EFFICIENCY	50 %	25 %
RELATIVE OUTPUT	0 db	-4.7db
DRAIN FROM 12V POWER SUPPLY	27.8 AMPS 334 WATTS	17.4 AMPS 209 WATTS
RELATIVE DRAIN	0 db	-2db

Fig. 6 - Comparison of transmitters.

SSB to have more power by some 2 or 3 db depending on assumed or measured efficiencies.

Expected Detected Signal to Noise Ratio Curves

In calculating the received signal to noise ratio, first the bandwidth of the receiver has to be assumed in order that the relative noise powers can be calculated. It is assumed that the single sideband receiver will have a noise bandwidth of 4.5 kc. This is somewhat larger than the 3.5 kc

necessary for speech transmission because a margin of approximately ± 0.5 kc has to be allowed for carrier instability. In narrow band FM, a deviation of ± 5 kc and a 12 kc bandwidth is assumed. In wide band FM, a 15 kc deviation and a 35 kc bandwidth is assumed. Based on these assumptions, the noise power of each of the three receivers under consideration is tabulated in Figure 7.

Figure 8 presents the brief summary of the assumptions made including transmitter power,

	SSB	NARROW FM	WIDE FM	AM
DEVIATION KC	—	± 5	± 15	—
BANDWIDTH KC	4.5	12	35	8
(ASSUMING NF = 10 db) NOISE POWER WATTS	1.8×10^{-16}	4.8×10^{-16}	$14. \times 10^{-16}$	3.2×10^{-16}
- dbw	157.4	153.2	148.5	154.9
RELATIVE	0 db	+4.2	+8.9	+2.5 db

Fig. 7 - Receiver bandwidths and noise.

DETECTED SIGNAL POWER VERSUS NOISE				
	AM	SSB	FM NARROW	FM WIDE
CARRIER WATTS	20 ^①	20	60	60
POWER dbw	+13	+13	+17.7	+17.7
NOISE POWER dbw	-154.9	-157.4	-153.2	-148.5
ATTENUATION OF CARRIER TO MAKE IT EQUAL TO RECEIVER NOISE db	167.9	170.4	170.9	166.2
RELATIVE RATIO OF DETECTED SIGNAL TO CARRIER POWER db	-3 ^②	0	-3	-3
IMPROVEMENT FACTORS ALLOWED				
	SSB & AM	FM (NARROW)	FM (WIDE)	
PRE-EMPHASIS db	6.8	10.7	10.7	
FM IMPROVEMENT db	0	8.9	18.8	
TOTAL	6.8	19.6	29.5	
① BASED ON SAME SIZE EQUIPMENT AND EQUAL TOTAL DISSIPATIONS.				
② AM IS PEAK MODULATION LIMITED SAME AS FM.				

Fig. 8 - Summary of assumptions made.

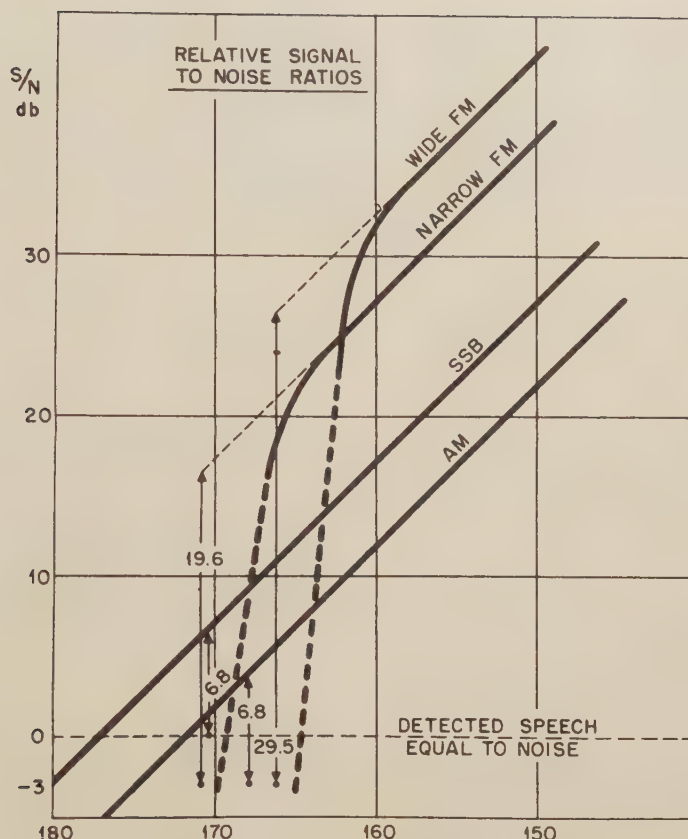


Fig. 9 - Attenuation between transmitter and receiver db.

noise power and relative merits of the systems, as well as the factors related to speech processing.

Finally, Figure 9 shows the signal to noise ratio as a function of attenuation in db inserted between the transmitter and receiver. (System attenuation.) From this figure, one can see that the single sideband system will give a somewhat larger range than both FM systems, but not much; perhaps only 10-30% larger because the attenuation increases some 16 db per range octave in the fringe area, and only if poor signal to noise ratio is acceptable.

On the other hand, in the strong signal area SSB will not provide as good a signal to noise ratio as the narrower band FM and particularly the wideband FM system.

Conclusions

In comparing FM and SSB equipments for the VHF mobile service and assuming equal equipment size, we can draw the following conclusions:

1. The relative performance of single sideband and FM systems depends considerably on the amount of speech processing. SSB should provide somewhat better range if a minimum S/N ratio can be tolerated.

2. In strong signal areas FM systems will provide a better signal to noise ratio than SSB

systems. However, this FM advantage in mobile service may be disputed, since once we have a good signal, exceptionally good signal to noise ratio is not necessary for intelligibility.

3. Consumption of primary power will be less in a SSB system than in FM system of equivalent performance.

4. It is expected that speech transmission through a SSB optimized system should in average be somewhat less distorted than in an FM system.

One very important point, namely the frequency spectrum savings I left for the end because it is so controversial. To some, the SSB is such a narrow band that it covers very little spectrum. Others believe that the transmitter spectrum splatter, which is a result of transmitter distortions, will be so bad that it will result in the wasting of frequencies.

These factors have to be carefully evaluated in the future.

It is my opinion that with the imposed proper limitations and control of the transmitter distortion and splatter, the single sideband could provide two or three times the number of channels as compared to FM system.

To sum it up, single sideband equipment has a good chance of competing in the future with FM

in mobile service and will provide as good or possibly better range with some frequency spectrum saving; however, its advantages in practical voice communication systems are not as great as one would suspect from some superficial comparisons of both systems as done in the past. Also, it is realized that there are quite a few problems to be solved before good, practical and stable single

sideband equipment can be developed and produced. There are such practical problems, as, for example, good AGC to combat flutter, also ignition noise which seems to be more severe in narrow band SSB system and which has to be eliminated by shielding of the ignition system or by additional impulse noise elimination circuitry in the receiver. These problems may delay the wide SSB application.

SEVENTH NATIONAL CONFERENCE

IRE PROFESSIONAL GROUP
ON
VEHICULAR COMMUNICATIONS

Session VIII -- 3:15 P.M.
SINGLE SIDE BAND PANEL DISCUSSION

"SINGLE SIDE BAND AM FOR MOBILE COMMUNICATIONS?"

Moderator: Dr. Austin Bailey, Chairman PGVC Awards Committee
American Telephone and Telegraph Company

MR. ANGUS A. MacDONALD: Gentlemen, this afternoon we have a panel session entitled "Single Side Band AM for Mobile Communications?"

Dr. Austin Bailey, with whom you are all acquainted, is going to be the Moderator of the panel, and on the panel we have Mr. Curtis B. Plummer, Mr. Henry Magnuski, Mr. Karl L. Neumann, Mr. Jerry Smith, and Mr. Joe Keller.

I will now turn the meeting over to Dr. Bailey.

MODERATOR BAILEY: Now that we have the formalities completed, we are ready to go to work. The panel has been introduced to you and you know what the subject is.

However, before we get started, Mr. Angus MacDonald suggested that perhaps we ought to put our feet on the same piece of terra firma and get a common take-off point so we could all be together on some of the things that I know will be "old hat" to a lot of people here. What I am going to say doesn't come in the category of anything but a brief kind of a historical resume which will take about two minutes; then you can have a go with these fellows.

Now, some of you perhaps remember that back around 1920 there was a very learned scientific discussion as to whether such things as side bands in radio actually existed or not. That seems strange perhaps, to some of us, and frankly, all people associated with radio today do not question the existence of side bands in radio.

Now, you will remember that an ordinary broadcast signal -- and I hope you will be able to see this little demonstration -- consists of a carrier and two side bands (DSB, Figure 1). Now, the carrier doesn't transmit any intelligence, and we can take that out. Both side bands transmit the same amount of intelligence, equally. So, if we take one of those away (SSB, Figure 1), we have a single side band left. Now you know what we are talking about.

The single side band carries all of the intelligence. The single side band suppressed carrier type of transmission, which was patented by John R. Carson back in the early 1920's, has long been used on telephone wire circuits, and the advantages which accrue from its use are pretty well

understood. They have been discussed by Hartley, Heising, and others--such as the people on this panel today, who can discuss it, further and more completely than I will. But I think that there are two or three things that we might say about it.

Since we have to transmit only one side band, we don't need to use the power of the transmitter for the carrier or the other side band, and in addition to that there are other advantages. There is an advantage--at least as illustrated in Figure 1--of frequency space saved.

There is also something to be said about decrease in the amount of distortion in the signal output that you may get by employing single side band as contrasted with double side band transmission.

The power gain, as Mr. Magnuski has already pointed out--if you put it on a straight power basis, is 9 db, and this, of course, has been very fully confirmed by experimental proofs--verified by very extensive transmission tests.

Now, the first commercial use of single side band radio was put into service on January 7, 1927. This was on the New York - London circuit on 60 kilocycles. Please get that -- 60 kilocycles -- a very low frequency. At that time, work was already under way to extend the use of single side band up to higher and higher frequencies, because everybody recognized at that time that there wasn't very much frequency space, and

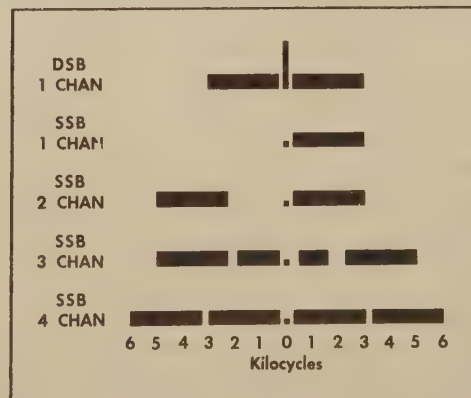


Fig. 1 - Overseas frequency utilization.

we were going to have to move up into the higher frequencies. I think perhaps one of the members of the panel will have something to say about that.

It was also shown by further, rather extensive tests, as you move to higher frequencies this question of the re-supplied carrier necessary to demodulate the signal was a very exacting requirement. Tests showed that you could resupply the carrier either up to 50 cycles above the suppressed carrier--which would be the zero frequency of the voice band--or maybe as much as 20 cycles below, and you would get speech without appreciable distortion.

Now, the frequency stability required for re-supplied carrier on two sides of the Atlantic, or two distant points not connected in any way, is quite a problem. It was finally solved by a combination of electro-mechanical gear. This made it possible to re-supply the carrier, and when the pilot channel faded, and things of that sort happened, you had enough memory in the gear so that the equipment would not go off hunting for the pilot frequency, but would wait a while and see if it came back.

Very recently, some of the work that has been done by the General Electric Company--I think they reported on this up in Utica--showed that the carrier frequency doesn't need to be re-supplied quite as exactly, if you are willing to--what was the phrase you used, Mr. Magnuski? -- about preparing the speech?

MR. MAGNUSKI: Processing the speech.

MODERATOR BAILEY: Yes, processing the speech. If you process the speech in advance by cutting off the low end, then you only lose the naturalness of the speaker and not too much of the intelligibility of the speaker. Now, that ought to be helpful in trying to do a single side band job in higher and higher frequencies.

However, there is one thing that we don't want to lose sight of -- and this was mentioned, too, by the speakers who have been on the platform and have already given their talks on single side band -- we don't want to lose sight of the fact that level differences at the receiving point are tremendously important in considering the advantages in frequency conservation that you get from the use of single side band transmission.

On point-to-point circuits, where the received level of all the signals that you want to transmit between one point and the other is substantially the same, you can obtain a really remarkable advantage from the standpoint of saving in frequency space. At the present time, on single side band overseas circuits, the situation on many of the circuits that are used today is -- and I will illustrate this-- that we put in a suppressed carrier, or a pilot tone, and then we put a side band on each side of that, which are not from the same speech source; and then we put in a little filter space to keep them apart, and then we put in another side band--another telephone

channel here--and we put in another telephone channel there. We have a total of four independent and separate telephone channels, all going from one point to another point. (Figure 1) This is in constant, daily use on short waves up to, as I said, about 20 megacycles.

The amount of frequency space occupied by those four telephone channels is 12 kilocycles. Each channel itself is 2.7 kilocycles wide, and then there are 250 cycles in between each channel, and two times 250 in the middle. That gives you some idea of the frequency conservation that it is possible to get on point-to-point service, and the kind of thing that is being done right now. I am sure that the members of this panel will want to discuss this question of level differences much further than I am going to discuss it now. There are other matters that they will want to discuss, and I think they should rightfully discuss.

There will be such things as the situation that comes about because of standing wave patterns in urban areas, and lots of problems in the radio transmission. I hope the people in the audience will ask a lot of questions on that.

Now, we will get down to the business of the day. I would like, first of all, after furnishing this general take-off point, to call on each one of the members of the panel to make a few remarks by way of introduction. Then, after they have each had a chance, it will be your chance. I will then call upon the members of the symposium to fire their questions, and I will request, if possible, that you direct your question to some individual member of the panel. After that has been done, if it is necessary, other members of the panel who may have contrary views, or may have something to add, will be welcome to do so. I do request, however, that you address your question to one individual member of the panel, because it will be helpful in carrying out this discussion.

First of all, I am going to call on Mr. Karl Neumann. Captain Walter, who was to have been on the panel, is in the audience, but he hasn't any voice. He didn't bring it with him. He just arrived without a voice. Mr. Neumann, unlike the other members of the panel, hasn't had a chance to say anything yet. We are going to call on him first to let him say what he has in mind. We will be a little more lenient with him and give him a little more time, because these other people have all had an opportunity to talk to you before. Mr. Neumann.

MR. NEUMANN: Thank you, Doctor Bailey. There are many controversial issues here that should be discussed, so I will keep this very brief.

I think it may be of some interest if I outlined some of the work done by RCA in the allied fields, namely maritime mobile and low power point-to-point services.

Most of the United States maritime telephone systems, involving about 45,000 boats and some 35

coast stations, use the 2 to 3 megacycle band for short ranges, or the bands up to 24 megacycles for long ranges. The FCC has requested that a study be made by the maritime interests to plan for single side band with the objective of spectrum economy and ultimate availability of more channels. An industry government group, the Radio Technical Commission for Maritime Services (RTCM), appointed a special committee about a year ago. This committee has completed a report, and I will briefly refer to that later.

Besides the mobile services there are numerous applications, especially in foreign countries, for medium range point-to-point radiotelephone systems in the 3 to 15 megacycle band. Conventional double side band sets having antenna power to the order of 50 watts have been used in such services. More recently RCA has been producing a single side band set, known as the SSB-1, that provides in one compact unit 60 watts of peak envelope power output on four pretuned channels between 3 and 15 megacycles. The carrier and unwanted side band are each suppressed by 50 db, while distortion products on a two tone test are down approximately 26 db.

In a small phone set of this class the most important problems were low cost crystal oscillators and the filters to pass the desired side band. The crystals, running in temperature controlled ovens, have a stability of five parts per million from -30 degrees to +70 degrees Centigrade, which means a maximum change of 75 cycles at the highest output frequency of 15 megacycles. This stability can be improved to the order of two parts per million with slightly better temperature controlled ovens. The first balanced modulator in this equipment is centered at 250 kc and is followed by a mechanical filter that passes the band 250.3 to 253.2 kc. By operating on a simplex basis, namely transmission and reception on the same frequency, it is possible in equipment of this type to use the same crystals throughout the transmitter and receiver. An additional receiver can be installed if duplex service is required.

We have made several field tests with the SSB-1 for ship to shore or point-to-point communication and the expected improvements were soon evident. The set consistently outperformed 75 watt carrier power double side band transmitters and with multipath propagation it often gave a higher grade circuit than 1 KW DSB transmitters. In another series of tests, four stations were established at Rocky Point, Long Island; Wildwood, New Jersey; a third at Washington, D. C., and one at Alexandria, Virginia. With this four party line set-up, all on the same channel, there were no heterodyne interference or blocking problems that are normally evident with double side band. Although each set has a panel control to vary the second crystal oscillator by plus or minus 75 cycles to compensate for drift, we found that it was not necessary to use this control during any of the tests. This panel control is called the "clarifier", to which my colleagues here have already referred. However, as I just commented,

during the test it was found that the stability was such that this control was not required.

I would now like to refer briefly to the RTCM report on single side band for the maritime services. Since most of the vessels and coast stations are now using the double side band in the 2 to 3 megacycle band, it is evident that compatibility becomes a major objective. The special committee has recommended that ship sets in the future be capable of using single side band with suppressed carrier when the other end of the circuit has single side band facilities, or be able to reinsert the carrier when the other station has only a double side band receiver.

Likewise, the ship must be able to switch its receiver to either single side band or double side band signals. The coast stations must, of course, be fitted with suitable single side band transmitters and receivers. If the program as recommended is accepted by the FCC, each coast station would initiate the single side band service on one of its present double side band channels and still retain double side band service on that channel for a limited period. As more and more ships get single side band equipment, the channel would finally become solely single side band. A second channel would then begin on a double side band-single side band basis, and ultimately shift to single side band. Probably one channel in each area will remain indefinitely on double side band in order to serve small pleasure craft and foreign flag ships that cannot afford the more expensive single side band set, or cannot very well make that changeover.

Turning briefly to the mobile vehicular field where frequencies much higher than 15 or 25 megacycles are essential, it is obvious that stability and other problems become much more severe. However, only a few years ago these same factors appeared beyond economic solution aboard ship, and perhaps the ice has been broken for further refinements that will aid vehicular communications.

MODERATOR BAILEY: I really don't know in what order to call upon the members of the panel, but I think I will now ask Curt Plummer, who may have some further introductory remarks to make.

MR. PLUMMER: I was glad to hear you talking about the marine field. I think you all realize, under the Communications Act, there is a section that says we shall develop further uses of radio--develop or encourage, I think, are the words--we all feel that with another international conference coming up, we would like to feel we are world technical leaders in radio, with all due respect to my British colleagues here--and that it is time to take a real look at going further in single side band below 25 megacycles.

As Mr. Bailey pointed out, the fixed users have been in for quite a while, and it is growing, and we are proposing it for aviation. We have already put out proposals and are very pleased to see that the aviation industry is really working on it, and now that the marine industry feels

their time is coming. I am doubly pleased that without any prodding, you are thinking about it in the land mobile field.

Of course, we are very hopeful, as usual, that we can get more people in business with more radio, and if we can get more people on narrower channels, then we are making progress. I don't think that it hurts the equipment manufacturers, either.

MODERATOR BAILEY: I want to call next on Mr. Smith from the General Electric Company.

MR. SMITH: There was one comment Mr. Monk made, which I think sums up the situation admirably, and that was about all the things we don't know about the goodness or badness of single side band. We need more field tests in the mobile services to determine how good single side band is going to look to us on 20 or 30 kilocycle spacing, which is presently the narrowest spacing envisioned in our usage.

As I stated in my paper, I think FM holds a pretty good position at these spacings, and there is no reason to believe there will be any loss of this position to any other form of modulation. If closer spacing becomes desirable--and I think it probably will--we may be able to gain some bandwidth advantage by using single side band. However, we do need to look into the thing carefully to see what limitations, if any, are going to result from using single side band.

Mr. Neumann in his discussion about the use of single side band in the maritime services indicates it has had very good results, and probably that is the place we will be able to get a lot of information from. Some of the limitations, though, that we are going to experience in the mobile services are not severely demonstrated at the maritime frequencies, because they are dealing with up to 15 kilocycles spacing and the stability problem is immediately tripled if you go even to low band.

I agree with Mr. Plummer, we should do everything we can to improve the spectrum of mobile radios, and I think certainly we ought to try this above 25 megacycles, as well as below, and if we are able to do it in the right order, we should go into the thing slowly from the lower frequencies on up. I think there is going to be some gain made over a period of time.

MODERATOR BAILEY: Thank you very much, Mr. Smith. Now, Joe Keller is going to tell us something about the use of single side band from the users' point of view, and I am sure for the first time he will introduce this dreadful word "Economics" into the discussion. So, I will call on Joe Keller.

MR. KELLER: Thank you, Dr. Bailey. I think it is a real privilege to be surrounded by all this brilliant engineering talent on my left and on my right. I am just a lawyer, but I don't feel exactly at a loss because I deal with engineers all the time.

I am anxious to make this statement now, that the users are deeply indebted to the manufacturers for the research work that is being done in this and many other fields. I think we ought to take a look at every possible avenue for increasing facilities for communications in all of the mobile fields. If we look very quickly over the history of the development of this field, we have come a long way.

FM was really the thing that made the mobile field possible, and our office, interestingly enough, represented Major Armstrong during the entire time when he was trying to establish FM, and it was not an easy thing to establish it. Yet, we have all been beneficiaries of the enormous development and the great impetus in expanding the frontiers of knowledge in that particular field.

Again, from the users' standpoint I would like to say that all of the users--and I think I know most of them--are anxious to cooperate in any way possible. Mr. Smith mentioned something about some field tests. I hereby say that we will be glad to cooperate with any manufacturer or any group of manufacturers in this or any other field.

You perhaps recall the work we did on split-channel operations as a user project, when we ran extensive field tests to establish whether or not the equipment was available and whether or not it was feasible to have split-channel operations in the 25 to 50 megacycle band. When the results were all in, it was the user group which went to the Commission with a formal petition. We didn't wait until the Commission came out with the proposed rule-making, but the users went to the Commission and said, "We are ready for split channel operation." As a matter of fact, we had been using equipment and had been putting in equipment for a long time to make it possible to have split-channel operation.

In the single side band field, I have been following very closely the developments of RTCM. I have been a member of RTCM and its various committees since its creation, and the things being done in the maritime field in single side band are very exciting and very encouraging, and certainly these things can be carried over into the mobile field.

Dr. Bailey mentioned the question of economics. I take it what he means is the question of the cost of the equipment, and of course that is a reasonable factor to be evaluated, and it must be evaluated. You have to be practical in these things, but you have never found in the mobile field users who were stiff-necked and who said, "We only want the cheapest kind of equipment." Their standard has been, "What is the best equipment, and what will give us the best results, and what will also make it possible for other people to use this particular equipment, or type of radio communication which has been proved so valuable in all of these industrial and other mobile services?"

So that I say to you now, publicly, that the users pledge their complete and wholehearted co-

operation. We would like to see more work done in this and other fields. We are interested--and as Curt mentioned at lunch today about geographical sharing, we are interested in engineering systems more precisely than they are at the present time. There is a lot of waste in that particular field now, because communication or energy is being spilled over a large area where it would not be necessary to accomplish the transmission of intelligence.

I think that those things ought to be examined carefully. I hope that out of the discussion at this time will come some cooperative field testing work; also, some additional discussions and papers between the various groups, and within the user groups. Here we have a fine cross section of all of the user groups, but we don't by far have the number of people hearing this, that should be hearing it. In addition, as these industry meetings come up, they ought to have speakers of the caliber and talent of the people that are in this meeting to take the message to our people. With joint cooperation of that type, and with teamwork, certainly tremendous progress will be made in this field, and we welcome it. We look forward to it.

MODERATOR BAILEY: Thank you, Joe, very much. I don't know whether you got your slide back or not, but at least we have a blackboard for you, and I think that we will also call your attention to the fact that we have left the screen up, so that if you want to project any of those slides--particularly the last one--I am sure everyone here will be glad for a little review.

With those few remarks, I will now call upon Mr. Magnuski.

MR. MAGNUSKI: I would like to convey four ideas, and perhaps it will take me eight minutes, or two minutes per idea. I will try to be short. The last idea perhaps is the most important, so I will try to speak briefly to the first three.

First, in the beginning of my talk, I mentioned that I am only interested in single side band for mobile application for VHF band, 150 megacycles. Actually my experiments were made at 150 megacycles, so I would like to mention that I completely agree with the use of the voice clarifier at lower frequencies.

Let me make it clear that at five megacycles the frequency stability is 30 times better than at 150 megacycles. So, I am quite aware that the frequency stability at lower frequencies is such that you don't have to transmit the partially suppressed carrier, and you can really get the full benefits from the single side band.

I am not questioning the RCA approach at all. To the contrary, I think it is a very good one. All it requires is the oven; a very precise crystal oven, and the oven has to be put in operation one or two hours ahead to stabilize the temperature and so on. Could you imagine, gentlemen, such an oven being used in mobile service when the

car is moving from hot to cold weather and fast temperature changes occur?

Therefore, I feel that mobile conditions are entirely different, and we cannot count at the present--at least for frequency stability in mobile units--and we have to transmit on a partially suppressed carrier. That's Point No. 1.

Point 2 concerns the discussion on speech splatter or transmitter splatter. I would like to use the blackboard, because perhaps it is better

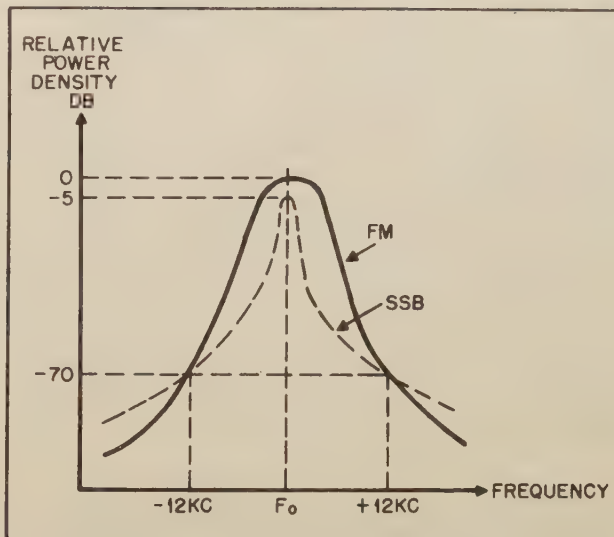


Fig. 2 - Transmitter splatter.

to illustrate it than to describe it in words. (Figure No. 2)

Gentlemen, I am sorry that I don't have slides to illustrate this, but if you remember the slide of Mr. Smith, this is more or less the sketch I want to introduce. In FM we are fortunate that the Bessel functions decide our splatter more or less, and we have a rather wide band at the top, but then a narrow band at the bottom. The FM system really doesn't occupy too much channel space. I will estimate that this point (where the two curves cross) is -12 kc, and perhaps +12 kc off frequency and at about -70 db level.

In single side band, first the power will be lower. If we take my assumption, it will be 5 db lower. Then, the splatter curve will be very narrow at the top, but then because of transmitter distortion, it will spread.

Now, this curve is very difficult to measure. First, I do believe that we have to use speech--real speech--in measuring this curve. Any speech imitations will not do, and I will tell you why. If we imagine the speech to be a single tone, then no matter how badly the transmitter distorts, there will be no splatter. There will be harmonics twice the frequency F_0 , and perhaps three times the frequency, but no splatter. If speech presents a pure, single tone at a particular moment, or perhaps if we transmit a telemetering tone or some-

thing like that--we have no splatter problem in single side band.

However, if we transmit two tones of equal amplitude, the splatter will be the worst. If we should transmit some noise, the splatter will not be as bad as a two-tone transmission, but not as good as single tone.

Therefore, to actually get this curve (illustrating) I believe we have to use the actual processed speech which we propose to transmit through single side band, and we may find out that this curve is somewhat better than some laboratory measurements so far announced.

Now, I don't want to be controversial about where this crossover point is; where FM splatter crosses the single side band splatter. This, of course, depends on transmitter distortion and we will have to keep the single side band transmitter distortion very low to get good results. This will be one of the problems to be prescribed by law, perhaps; the limitation on transmitter splatter to make the single side band usable. Let us suppose for a moment that this happens at some 70 db below this value, and some 12 kc off. Then we could use perhaps a 15 kc spacing in single side band. We know that 20 kc spacing is about the minimum which we can use in FM systems now.

The third point is that we should evaluate what this means; what this 70 db splatter in the next channel in actual operation of a mobile system means. I would like to make another drawing on the blackboard to illustrate this. (Figure No. 3)

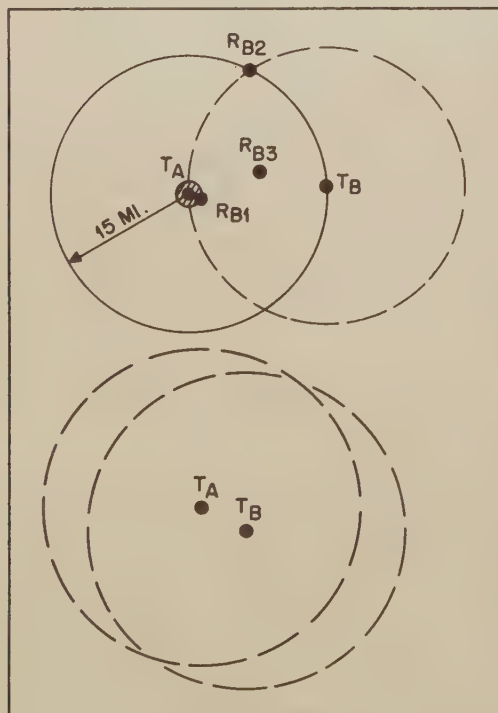


Fig. 3 - Effect of transmitter splatter on system operation.

Suppose we have System A, with Transmitter A, having a range of about 15 miles. Now, we know that this is about 160 db system. This means that 160-170 db of attenuation of transmitter power is required to reduce it, to be equal to receiver noise. We find that at 160 megacycles, only 1000 feet away from the transmitter, the power will be attenuated by 60 db. At a distance of about one mile, it will be over 70 db. So, the receiver B-1 has to be very close to the transmitter A to get a really strong signal.

Now, another problem. Suppose this receiver is also receiving interference? We have always to consider the ratio of interfering signal to desirable signal. Now, suppose that we have a second system (B) which is also a 15-mile range system--we have this receiver, B1 receiving from adjacent channel Transmitter B, which has to be on the edge of the range; then, of course, this receiver receives a signal which is just marginal; half a microvolt; one microvolt, or whatever it is. If the transmitter A is about 1000 feet away, it will have a 100 stronger db signal from this transmitter. Therefore, if the splatter is 70 db, the interfering signal would be 30 db stronger than desired.

Now, someone may think that this is very bad, but let us consider how often this happens. This can only happen if this station A is exactly 15 miles from the second station B, and furthermore, it will only happen in the neighborhood of A. Please notice that Receiver B3 or B2 will receive about equal signals, and will not be disturbed. Therefore, actually any larger than 15 miles spacing, or smaller spacing between transmitters will not give us interference conditions.

Now, let's be practical and let us think about the problems we have in communication. If we take a typical system in the country, we usually don't have too much interference, but where we are really badly squeezed is in the congested areas, in the cities. Suppose we have a city and we have some two taxicab systems. Well, chances are that Transmitter A is here (Lower circles Figure No. 3) and Transmitter B is here. Now, in this case, they are both trying to cover the same city. They are probably close by. In this case there is no interference in this system and this 70 db is plenty good, gentlemen.

Now, as to the last point, perhaps it is a bombshell, I propose a compromise. If I would have to use the frequency spectrum to its highest efficiency, what I would do is the following:

I would separate the base frequencies from mobile frequencies. Transmission from mobile frequencies doesn't have this advantage of freedom from interference if the base stations are located close by--I don't mean in the same building or anything like that--but, say, within a mile or two miles--they can really use a single side band from the base station to mobile unit on a very small frequency spacing; perhaps even 10 kc or something like that will do, because we will not have this condition that the receiver is trying to re-

ceive a weak desired signal close to the powerful transmitter on the adjacent channel.

Now, for each base station therefore, a separate frequency and single side band would be very good. Now, to reply from the mobile unit, FM has advantages because one transmitter can be close to B but transmitting to Station A, and the other transmitter can be far away transmitting to Station B. In this case there is no chance to equalize the signal. Therefore, a compromise system which will be the most efficient in spectrum use, would be single side band base stations and FM receivers.

MODERATOR BAILEY: Gentlemen, the question before you all is: Should Single Side Band AM be Used for Mobile Communications? The question mark is on the end.

QUESTION: Dr. Bailey, I want to compliment Mr. Keller very highly on his expression of the offer of industry to be of service in testing some of those things. I would like to direct my question to Mr. Plummer.

Mr. Plummer, would we be permitted under the FCC rules in patrolling radio service frequencies not now calling for FM use, to experiment with some of this AM single side band without special authorization?

MR. PLUMMER: Yes. As a matter of fact, almost all of your rules are written out so we could authorize it.

QUESTION: Would that happen if a police station made such an application?

MR. PLUMMER: We are granting them, but on lower frequencies, you understand. I am talking about this modulation clause that says, "AM, FM, or other modulations."

QUESTION: I may ask Mr. Magnuski a question, because as he was talking, I was putting the two things together in my mind.

MR. PLUMMER: I have had some of my boys charting out the 152 to 162 megacycle band, at 15 kc increments. We found there are some discontinuities in trying to channel it out, due to the fact that the marine has 100 kc channels, so you get certain discontinuities at the ends. At the lower industrial end, there is 100 kc, and then there is another asymmetry where the spacing between carriers is different on one side than on the other. So, therefore, there are some bits and pieces of 5 kc and 10 kc increments left over, in the 152-162 megacycle band.

QUESTION: Putting together what Mr. Keller and Mr. Magnuski said, why not mark those pieces of 5 kc and 10 kc increments for single side band use? Eliminate the development stations, and just mark them right off the bat in the set of rules, and let people use them for what they are worth? If it turned out that the apparatus is no good, you can always send it back to the manufacturer.

QUESTION: I have a question for Mr. Magnuski. I would first of all like to make an observation on his bombshell. It strikes me that one important advantage is that the place where you can most afford to set high standards and narrow stability and so on, is precisely in the central station. So, if you have a central station which has single side band--a single side band transmitter and FM receiver--with the reverse at the other end, then certainly you solve a good part of the problem.

But the other part of the problem would be stability in the mobile receiver, and from this point I would like to ask a question which is going to reveal my ignorance of this whole single side band problem, but maybe I share it with other people here. The question is, what does a pilot carrier system require in the way of stability as against--well, a nominally complete suppression of the carrier? You were talking about a pilot carrier, let's say 20 db down. Well, will such a system permit you now to have the same sort of stability that we have now, and to use some phase locking system?

MR. MAGNUSKI: Your observation is very correct. The base station stability can be very good, and because of the base station stability, we can put the base stations very close by.

To return to Mr. Plummer's remarks, actually, we could get it on these small spacings when we have larger bands for several base stations; let's say, 50 kc for five different channels for base stations assigned to it. One channel of 10 kc won't do us much good, because other stations will interfere. Actually, the end of the channel is not usable because other services may disturb us. So, if we would have a separate band, perhaps very narrow, for the base stations, we could do it.

Now, as to the mobile receiver and the carrier--there are actually two systems. One is the locally generated carrier in the receiver. This, I believe, wouldn't be stable enough in high frequencies. So, you cannot use this system. The best way would be to transmit a partially suppressed carrier. This carrier can be suppressed, say, 20 db, 15 db, perhaps. That depends on how well advanced circuits we use. However, it is possible, since this carrier is stable and doesn't carry the information--it is possible to devise the receiver circuit which will phase lock. Its locking oscillator is similar to that used in color television, in the color carrier, and once it is phase locked this oscillator will be on exactly the same frequency. You can transmit tones; you can transmit anything--you have no error in frequencies in this case, and all you have to do is to devise the circuit which will fish out this carrier away from noise--20 db below noise, and phase lock the oscillator which is used for it. Now with this circuit which can be done, and it has, there is no stability problem.

QUESTION: I have a question for Mr. Magnuski, with reference to what he was just talking about,

and comparing it to color television. Would there be any advantage in keying this suppressed carrier as it is done in color television--would there be any saving in stability or in bandwidth by keying it as in color television?

MR. MAGNUSKI: I don't believe so. Actually, this circuit, the way we have it, takes advantage of integrating over many cycles. The carrier always adds up and the noise is gradually eliminated. So this keying, which is a necessity in color television, doesn't help the circuit. This circuit is not exactly the same, but similar. I just gave you the idea of a phase locked oscillator continuously locked on a very weak carrier transmitted with noise.

DR. BAILEY: I would like to ask a question if I may, while you are right there. What happens when that phase lock--or, rather, when the suppressed carrier disappears with this phase lock scheme?

MR. MAGNUSKI: You have a great big burst of noise from the receiver.

MODERATOR BAILEY: That's all I wanted to know.

MR. MAGNUSKI: However, I would like to add to my answer, this circuit has a certain memory. I will demonstrate it this way. Suppose you have a receiver locked on one carrier and suppose another carrier shows up, say, 200 cycles away. The receiver will not jump to this carrier. This carrier may be 15, 20 db stronger than the carrier on which it is locked, because the phase lock will keep it away from jumping. In other words, this carrier has a certain, should I call it "memory", or certain "capture effect" or whatever you want to call it, that once captured by one carrier, it is difficult to get it to jump to the other carrier. That is why it is possible to receive relatively low frequencies in the side band and still have this carrier and the lock oscillator working properly.

QUESTION: My question is directed to Mr. Magnuski. Now, considering only the matter of conserving band width, if you were to transmit a signal on single side band, either full carrier or carrier reduced by, say, 6 db, will you lose many of the advantages of single side band?

MR. MAGNUSKI: Definitely. That's why the proposition is to make a receiver circuit which will accept the carrier 20 db or 15 db below. If you transmit a full carrier, or 6 db attenuated carrier, you have no benefits as far as power is concerned, from single side band, and the splatter becomes very much worse, because it corresponds to two-tone modulation. It is not as bad as when you transmit two side bands, but it is quite bad. So, what I am referring to, is to the system which utilizes a suppressed carrier by some at least 15 db and perhaps 20 db.

QUESTION: I want to ask Mr. Smith a question, and that has to do with some experiments which you

will recall, in which there were some published figures made of mobile communications in city streets where a single frequency carrier was transmitted, showing a standing wave pattern very definitely in the matter of perhaps every 30 feet. There was a complete drop-out of a carrier. With this suppressed carrier method of operation and with the information that Mr. Magnuski has furnished on the noise that will come in when the carrier disappears, in your opinion, is it likely that we get the signal to noise improvement that the suppressed carrier method otherwise gives us?

MR. SMITH: It is my opinion that you lose the signal altogether. You will only have the noise in its place. This is one of the things that we need a lot of field testing to determine. There are a couple of other things I wanted to say, however, while I have the floor here.

While Mr. Magnuski's remarks here on the way transmitters may be spaced in the city points a moral with which you cannot quarrel, as it says in the famous song, I don't think we ought to underestimate the difficulties likely to occur, say, in a taxi service, if you do have what I classify in my paper as "nuisance splatter." You recall I said you might be able to solve the problem by application of tone squelch, or something of that sort, but if you do have a receiver running wide open, while it is true you receive a strong signal for recapture and getting you back into shape, you will be in danger of getting splatter, and there are some limitations as far as tone squelch is concerned about knowing when you have a clear channel, that may make you have more interference than you desire, because you think you have a solution to the problem.

Another thing in the matter of splatter that you may get, if it were described what the splatter ratio would be, we may lose some of the power economics ratio that you can get by single side band, because to get really down far in db, you have to cut the grid drive pretty seriously in order to pull it down from 30 or 40 db, to 60, 70 or 80 db. A real severe reduction is necessary in order to decrease the amount of splatter due to non-linearities, in the amplifier to the level considered acceptable in present systems.

On stability, and the problem of whether you should use a phase locking system or whether you should use a pilot carrier, I think the economics point to the use of some system such as phase locking, but it is strictly a matter of economics. There are other types of systems to obtain frequency stability, but the phase locking system is very good and it is used with double side band, carrier suppressed, in a very good manner for getting information from two side bands to determine where you reinject your carrier. As you know, you have to have your carrier not only in frequency, but also in phase synchronism, in that system, and we have used that and found you can hold it in so you can get good results.

QUESTION: I have one question to Mr. Magnuski. He showed on his curves earlier that if we

are willing to accept 10 db or less signal to noise ratio, there is an advantage up to 8 db for the single side band, assuming there is no outside interference. Did you have any data or tests there where you had impulse noise, and how much of that 8 db did you lose when there was outside noise like impulse noise entering the picture?

MR. MAGNUSKI: I will answer your question in just a moment. May I just comment for a moment on Mr. Smith's remarks. I completely agree with all three points. One point was as to frequency stability in the mobile unit. Obviously, we cannot wait, say, one hour, until the oscillator warms up when we have to transmit the message.

The second point. It is obviously true that we have to have some negative feedback in the transmitter, or something, to keep the distortion down, and we may lose some power. Fortunately, actually the distortion curve has a sharp knee and I don't believe we have to lose too much power to reduce distortion. This, again, is a very good point, and I completely agree. However, I believe a practical compromise could be worked out.

I forgot to mention that in measuring this splatter and distortion, we are using a tape recorder with a typical sentence (speech) on the tape running continuously. Then we take this sentence and process it; clip it, or whatever we want to do, and then put it in the transmitter and then measure the splatter. We found this is the only true method, and with two-tone or any other method of measurement of splatter, I think the results are not quite realistic.

Now, to answer your question about the noise, actually all noise can be divided into two types. One is the white noise, which is more or less continuous with time, and the other is some kind of impulse noise which has sharp, short bursts, and there is nothing in between. Now, the impulse noise is a problem and if you have impulse noise, I neglected to mention or just started to mention it when I made my talk, if you have impulse noise, this 8 db is not necessarily true. You can't devise a circuit which will remove substantially the impulse noise from the receiver. However, I completely agree that the impulse noise with narrow band single side band receiver is a worse problem than, say, in an FM system, and perhaps economics will go into the picture and we will have to have additional circuitry to remove the impulse noise from single side band receivers.

QUESTION: I have a question for Mr. Plummer, but before I can ask the question, I have to display a little bit of my own philosophy and thinking. We are all talking about a subject which is way out in the future at the moment for us, and I know an awful lot of people have in the back of their minds, how will you ever accomplish such a change, going from FM to single side band? I suppose most of them regret the thought of throwing everything out and starting all over. So, if we are looking for new communication systems, how can we fit this into the long range thinking of the Commission?

So, I would like to ask this particular question; in view of the fact that there have been many statements made that we would like to see TV move around to a different place, or perhaps the FM broadcasting move somewhere else--in view of the fact that we have not made actual mobile tests on a long range basis in the area of 100-150 megacycles, would it be possible to fit this in with the thinking of the Commission and actually perform field tests where you could run these tests with customers using these frequencies; using single side band, or suppressed carrier double side band or $2\frac{1}{2}$ kc FM systems, to get a measurement not only of the various modulation techniques that might be used in developing new bands for two-way mobile, but also to get a measurement of the practicality of that band for mobile frequencies?

MR. PLUMMER: That's a mouthful of question. I think, at the moment, as I was talking to Mr. Barnett, our rules are written to allow some of that on a commercial basis. As I say, our rules, as far as channeling goes, in the recognized channels, say, "AM, FM, or other modulations." We have been surprised that more people have not come in on a commercial basis and asked for some of these other modulations. We have had one or two in the police field. I don't see why the rules couldn't be reworded, perhaps, to make it clearer.

Now, the second thought; in connection with that we have been wrestling with and trying to write some words, as to the relationship of this when we implement channel splitting. There are in the present channel, 30 kc points and 15 kc points. Now, I know that different industries are going to want to implement that in different ways. Some of them are going to want to hold off on the 15 kc points, and some of them are going to try to use them immediately. I think there is a possible wording there that you could accomplish the two things with a minimum of grief. I don't know what it is yet, but I have had some boys trying to write out a rule along that line, so if you have any ideas, I will be glad to have them.

QUESTION: My point is perhaps the best way to approach it would be in a whole new band. In other words, in the marine situation, going from double side band to single side band, you have a method of evolution, but there is no method of evolution from FM to single side band. You go from one to the other. You can't modify a unit readily, or put a kit on, and turn a key or something and go from one to the other. So, might we not consider this on the basis of developing new band use; using a new type of modulation? Don't decide this moment on single side band, but examine it, and examine narrow band FM and perhaps double band suppressed carrier systems as well?

MR. PLUMMER: Of course, I think the problem is getting the new band. I can see to do it by moving some people a little bit.

QUESTION: If you are doing long range thinking on this point, you will have to do long range thinking on where the bands are going to be.

MR. PLUMMER: I think in channel splitting, inevitably there is going to be some moving, because I think there will be two philosophies. One will say, "Squeeze us all up together, if we are stuck with split channel." The other philosophy will say, "Let's leave them, and edge in with the new ones." To me, it's almost a toss-up, but in the case where somebody wants to squeeze up, I can see where a piece of band might be open, say, in the 152-162 megacycle band.

QUESTION: Mr. Magnuski, what sort of an exciter or transmitter did you use for generating your single side band? Was it a phasing type, or filter type?

Another question: Inasmuch as you are only passing 3 kilocycles, was it necessary to have a four-and-half-kc pass band in the receiver on single side band?

MR. MAGNUSKI: We use, of course, the filter type system. What we actually use is a generator on a frequency of 455 kc. We have a balanced modulator and a mechanical filter, 3 kc wide, which separates the side band for this system. The rejection of the mechanical filter--it rejected, if I remember correctly, 20 db, the carrier. Even the low frequencies, in the second side band, 300 cycles was rejected over 60 db, and the entire side band was close to 100 db rejection.

To answer your second question, I assume $4\frac{1}{2}$ kc for a receiver band width, because the receiver has to allow for frequency drift and we assume--plus or minus 500 cycles of frequency drift for the system. The receiver band has to be wider by 1 kc to allow for this frequency drift.

QUESTION: One more question. We are talking about stability of 20 or 30 cycles, and you are still saying, "500 cycle drift in the pass band." I don't quite understand that.

MR. MAGNUSKI: All right. The FCC rules require 0.0005% in the 150 megacycle band-- I believe. At 150 megacycles this amounts to plus or minus 750 cycles. The 30 or 20 cycles refers to 5 megacycles or some other low frequency--not exactly low, but HF transmitters. You can get the stability at low frequencies, but at 150 megacycles we consider that we are doing a little bit better than the FCC requirements by having overall stability between transmitter and receiver in the amount of plus and minus 500 cycles. We have actually done better than that, but you have to have some leeway and some safety factor. We have stability of the order of 0.0002%, but we have to allow something additional in case something goes wrong.

QUESTION: Mr. Magnuski and I talked this over before, but it might be a good idea to put this question from the floor. In the use of mechanical filter, 455 kc, to generate your single side band, I believe you stated you had a second conversion then, going somewhere in the 5 or 10 megacycle range, to move your image out far enough that you could get additional isolation. It is

my feeling, and our feeling, that perhaps this is the proper frequency to generate your single side band, using a single crystal filter, somewhere in the 5 to 10 megacycle band, rather than starting at 150 kc.

Incidentally, have you run any tests at all, instead of using suppressed carrier, using pilot tone--3,400 and 3,700 cycles? Does this mean easier phase locking on the local oscillator at all? The problem bothers me.

MR. MAGNUSKI: The first question, I completely agree with you that a crystal filter could be used to generate single side band if the sides are steep enough. However, we didn't have it available. Perhaps it will save a few stages of amplification to get to the higher frequencies. This is a question of economics, and I agree with you that perhaps in the future crystal filters will be easily available and we will not use mechanical filters on low frequencies to do that. That is quite possible.

Your second question as to the pilot tone, instead of a carrier frequency--it isn't economical. Actually, it amounts to the same thing, because the side band is an independent group of frequencies, and the pilot tone below or above the side band doesn't make any difference to a receiver. However, to generate something else than carrier frequency, you have to have additional equipment which will offset this tone versus carrier frequency, and in the receiver additional equipment to convert the tone back to the carrier frequency. Now, if you use carrier frequencies, you have a very simple circuit, with lock oscillator, and it requires very little additional circuitry and is very economical. The suppressed carrier is better, simpler and equivalent to any tone you can use.

QUESTION: Mr. Magnuski, has there been developed for single side band, a squelch that is satisfactory to its operation, as there is now for FM?

MR. MAGNUSKI: This is actually a comment to the question I wanted to speak about in connection with Mr. Smith's remarks, and I am sorry that it escaped me. He mentioned squelch. Of course, when the burst of noise occurs, this squelch has to be very selective, or tone squelch or something like that to avoid interference in this proposed system. That's exactly correct. We have to have a different squelch than in FM for single side band.

Now, what should I say? There are quite a few AM type squelches available. Some of them could be used in SSB. Now, I hate to disclose too much about our progress, but you can imagine that if we have the phase locked oscillator, we can have quite a few circuits which recognize whether the phase locked oscillator is locked or not locked on the carrier and we use this for squelch. It is a very good squelch; very sensitive, and we feel that this will not be a problem in single side band operation.

Perhaps some other companies have some other idea of good squelch, and there are quite a lot of possibilities here, and of course all the systems will be squelched. They are always squelched, otherwise reception would not be possible, since nobody could tolerate the noise. So, we feel that a squelch will not be a problem, and nuisance interference with proper squelches will not be a problem in single side band operation.

QUESTION: This question is directed to Mr. Smith. Very briefly you touched upon the effect of multipath reflections in causing perhaps a suppressed carrier to disappear. I am wondering what the relative effects of this general multipath reflection is on FM versus double band, versus single side band AM, in attempting to suppress any certain frequencies at any given spot.

MR. SMITH: That's a question that's sort of in debate right now. There are some advantages that apparently are pointed out for having a double side band suppressed carrier along these lines, and there is work being done right now to determine whether the multipath distortion that you get isn't more of an advantage for being taken care of by virtue of the fact the two side bands do not suffer any of the same distortion. There will be more available on that subject later, but right now it isn't out.

There is another subject I wanted to say something about. Mr. Magnuski commented on it, and again, I don't want to belabor the point of adjacent channel interference you may get as a result of having distortion products, but there are two situations that lead to distortion products from the single side band and there are two ways in which this is taken care of. One of them is the situation that develops when you over-drive a linear amplifier, so-called, to such an extent that it gets into a serious non-linearity condition. You remember that I said it is possible even to get as bad as only 10 or 15 db down. This situation can be taken care of by a method which is often referred to as automatic load control, which in effect keeps watch on the amount of drive that you have so you don't get into this condition. However, you still have the situation regardless of whether you do use automatic load control, and even if you do use linear feedback to try to stabilize the transmitter characteristics of the amplifier, you still have non-linearity in the amplifier, the magnitude of which depends on how far you drive the amplifier. Even if you have the feedback and automatic load control, your products are worse when you try to get more peak power out of the situation than they are when you are satisfied with a very small number of watts.

MR. MAGNUSKI: Can I comment on this last statement? Again, I am in agreement this is a question of degree. However, fortunately, usually the amplifiers have a very definite point of overload, and we are not losing much power if we bring it close to the knee of the loading curve. Actually, past this point we have terrific speech distortions; very bad splatter, and we should always work below this knee. However, I feel that

loss of power, because we have to work below this knee of distortion, will not be too great. I agree in principle, but differ perhaps in the estimation of how bad it is.

I would also like to mention that selective fading does not occur in mobile communication. So, we don't consider this to be a factor in the system. The fading, of course, occurs in mobile communication sometimes, but if we have such fading, everything fades at the same time. We don't know which system is better for selective fading, and frankly in the mobile business we are not interested in selective fading.

I would like to mention in this connection that AGC is another problem in single side band receivers. FM is very fortunate because it has a constant output, regardless. You have to be very careful in designing good AGC circuits in single side band, and this is another problem which may delay single side band development.

I wish to correct the impression that single side band is immediately available--it is not yet available, nor will it be available tomorrow from the shelf. There is plenty of work to be done. There are good possibilities, but we have to improve, technically, the equipment. Of course, it will cost something, and we will have to pay a certain price for saving the spectrum. Perhaps the equipment will be a little bit more expensive and will require more precise development. Frequency stability, AGC, and ignition noise circuitry--these are all problems which have yet to be completely and satisfactorily solved. However, we can look into the future, and if necessary, the solution will be found to these problems.

QUESTION: There has been some discussion about the economics aspect, and especially as to the last point made by Mr. Magnuski. Now, it would seem to me that the transmitter--and this is just to amplify what I said before--could stand a good deal of refinement and still be an economical proposition from a system point of view.

One could have, for example, frequency stability of the order of 50 cycles and a fair amount of efficient use of power tubes so that you could have fairly low peak amp. load power in order to reduce the distortion, but the real problem seems to be in the receiver. So, that problem of squelch, AGC and so on, has to be considered from the economic point of view.

I want to raise one additional thing that bothered me about this receiver, and that is if it is possible, or, rather, if you are going to use a suppressed carrier in order to phase lock the local oscillator, then you want that suppressed carrier to be effective when you get out into the fringe area of reception.

Now, I just would like to throw in this little bit of calculating to Mr. Magnuski and get his opinion as to its validity. Suppose you had 20 db down in the pilot carrier, could you not conceive the receiver as having, say, two i.f. channels;

one 5 kc wide, and the other one of which would be just wide enough to accept the instability of the local oscillator--let's say, 500 cycles.

If that were the case and you had equal noise-power distribution, that would give you 10 db advantage immediately from that narrower side band, and then you don't need 12 db signal-to-noise; maybe you don't need 2 db signal-to-noise, so you have your 20 db right away. Furthermore, the pilot carrier is of no disadvantage on the fringe, as compared with the one on the side band.

I wonder if that is a valid concept or not?

MR. MAGNUSKI: Yes, but actually it is not exactly so. Let me put it this way. First, I agree that plenty can be done in the base transmitter, and if the base transmitter is stable and so on, and the problem of spacing base transmitters will not be too great. Perhaps even a 5 kc spacing would be sufficient, and we can have plenty of frequencies for the base transmitters. This depends simply on the distance between the different base stations. The larger the distance between base stations, the wider spacing we have to have to drop the splatter so there will be no interference between different receivers. This is as far as spacing is concerned.

Now, as far as the carrier is concerned. Now, the information theory teaches us that the carrier which is presumed to be rather stable, say over a few seconds time, contains no information, and we could theoretically fish it out from noise with extremely narrow band, say, one cycle or two cycles. The question is only to compromise how long it will take us to fish the carrier out of the noise, and that's exactly what we do.

For example, in this one embodiment of the circuit which we are using, it takes us about 50 milliseconds to lock, which is not bad. Before you press the button and start speaking--before you think what you have to say, 50 milliseconds elapse, and the carrier is locked. This 50 milliseconds corresponds roughly to 20 cycle band width. I am not precise in this assumption, but let's say 20 cycle band width, and obviously noise in 20 cycles is much less than in 3 kc, so there is practically no limit to the circuit, as to how well you can fish the carrier out of the noise, and in all receivers, the carrier is locked before the power in the side band overcomes the noise in the 3 kc band width. So, there is no problem, really, in fishing out this carrier if the equipment is properly designed.

It is a question of how far you can go in suppressing this carrier and in allowing delay in locking. It is a compromise between delay in locking and suppressing the carrier to get the proper operation and locking before you can distinguish the spoken word.

MODERATOR BAILEY: I would like to ask Mr. Neumann a question. This is a subject that hasn't been discussed here at all, and I think it should be. Have you done any thinking along the line of

what Doppler Effect in the single side band transmission will do to the resupplying the carrier signal?

MR. NEUMANN: In my particular field of endeavor the Doppler Effect is not a problem as yet. Ships do not travel at such a speed to cause any difficulty, but in aeronautical communications that is a definite problem, and I know there are some schemes under consideration to combat this extreme difficulty, but I am not too familiar with these schemes, so I am afraid I can't give much information as to what has been done along that line. I see a man here on my right who is very eager to answer this question.

MR. MAGNUSKI: I am sorry to bother you again, gentlemen, but this may be a problem in the future which we will have to consider. Again, a circuit locked on the carrier solves the problem, because if the carrier shifts, as in the Doppler shift, the locked carrier follows this shift and recovers perfectly the single side band without any frequency error, once the local oscillator is phase locked on the carrier. So, again, perhaps in the future we will have fast planes trying to use single side band, and we may have to transmit on partially suppressed carrier to provide for this Doppler Effect.

QUESTION: Operating on the very broad assumption that some day we will lick these problems, perhaps we can't realize just now the inherent advantages of single side band. I am somewhat concerned, though, about the impulse noise problem that is projected. If I understand it correctly, if this be the case, we can actually no longer gain the advantage of it becoming somewhat comparable to FM. This is perhaps the worst city in the world to ask this question, but unless you stick your neck out, you don't get anywhere.

So, I am wondering--particularly concerned with trucks--since we seem to be guilty more so than others, of generating lots of this noise--and I have seen lots of these reports, running up far and in excess of 500 megacycles in some instances--is there any consideration, Mr. Plummer, toward perhaps including vehicle electrical systems in your spurious noise radiation documents?

MR. PLUMMER: This is one of the very sad stories in the past.

Here about 1947, there was real cooperation between the auto manufacturers' association and the radio manufacturers' association on this whole subject, and we had a series of meetings of the two associations in Washington, and I have got to admit it was mostly around the television problem. I can't remember the details, but it ended up that the automobile manufacturers' association walked out of the meeting, mad, and that was the end of the cooperative effort.

Perhaps some of the people near to that situation can remember the reasons why, but I think somehow they would have to be brought together again.

QUESTION: I read on the program here, "Single Side Band", and "Advantages of Single Side Band or FM, or VHF Mobile Service", and from this program it would appear that we have our choice today of the two types of mobile units. I am more or less interested in the sales aspect. I am wondering about what the actual problem is before we will have single side band units? Will it be 7 years; 10 years, or 15 years? Is there anyone on the panel that could answer that question?

I am sure there are quite a few users in the room that would like to have some light on the subject.

MR. MAGNUSKI: Your crystal ball is perhaps better than that of any one of us. You have more to do with the field of sales, and nobody can really predict. Actually, I feel that if we are forced into the single side band, we could speed up the development and within the next year or two some equipment could be available.

Now, single side band, to sum it up, doesn't represent too much advantage. It represents lower battery drain, and the main advantage which we hope for is saving of the frequency band. Now, the saving of the band is very questionable, especially in the case of replying from mobile unit to base station, and the only thing which we could possibly save is this base station band saving. So, it is rather questionable whether we should go to the single side band.

QUESTION: I want to make two comments. First, about the gentleman who asked about pilot filters, or pilot selection. There are a number of manufacturers who are using that approach now.

The second question is to Mr. Keller. I notice that when you gave your talk, you said the users wanted the best and not the cheapest, and it seems the representatives of the manufacturers keep bringing up the point of the most economical use. Would you like to elaborate on what the problem area is?

MR. KELLER: Well, I am not saying that the users are anxious to buy the most expensive equipment available, but what I did say, I believe, is that the cost would not be a controlling deterrent

if the equipment that was available in this single side band field did a better job and made more facilities available. That's what I mean.

Now, all of these things are apt to be expensive in the beginning and that was true in FM, too.

MR. MAGNUSKI: May I comment on that? Actually, let's face it. We all agree that the best frequencies for mobile use lie between some 100 and 500 megacycles. We would like to have more channels very much. If we cannot get them at these frequencies, we will take 900 megacycles as the last resort. In other words, if we cannot do any better, we do need the channels very badly, and since the communication needs are growing, we will take what we can get. This is the base that Motorola is asking for assignments for mobile communication; possibly the lowest microwave frequencies, because at higher microwave frequencies we don't believe they are suitable for mobile use. Even at 900 megacycles, we say "Ouch," when we have to make a system.

MODERATOR BAILEY: Well, gentlemen, I think this could go on and on, and there are questions all over the place, and hands are up everywhere. But it is 5:00 o'clock. I am going to say that I think we have got to adjourn the panel, and I am sure that any of the panel members who are not catching planes and trains and checking out, will be glad to answer any of your questions individually. I hope I am not speaking wrongly for the panel.

We certainly have had a very interesting discussion here this afternoon, and I am sure that we have gotten a lot of viewpoints and ideas, and this may lead to future discussions.

This is a long-range, far-reaching, long-time, in the future, crystal ball kind of thinking as we all know, and we are all learning together.

I think that this has been a most beneficial meeting from the standpoint of the panel members, and I hope it has also from the standpoint of those of you in the audience who have participated in this discussion.

With that, thank you all, and "Good night."

